Vol. XLII AUGUST, 1923 No. 8

JOURNAL OF THE American Institute of Electrical Engineers

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PUBLISHED BY THE INSTITUTE
33 WEST 39TH ST • NEW YORK CITY

American Institute of Electrical Engineers

COMING MEETINGS

Pacific Coast Convention, Del Monte, Calif., October 2-5

MEETINGS OF OTHER SOCIETIES

American Electrochemical Society, Dayton, Ohio, September 27-29

American Institute of Mining and Metallurgical Engineers, Ontario and Quebec, August 20-31

Association of Iron and Steel Electrical Engineers, Buffalo, N. Y., September 24-28

Illuminating Engineering Society, Lake George, N. Y., September 24-28

JOURNAL

OF THE

American Institute of Electrical Engineers

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 West 39th Street, New York

Subscription. $10.00 per year to United States, Mexico, Cuba, Porto Rico, Hawaii and the Philippines; $10.50 to Canada and $11.00 to all other Countries. Single copies $1.00.

Entered as matter of the second class at the Post Office, New York, N. Y., May 10, 1905, under the Act of Congress, March 3, 1879. Acceptance for mailing at special rate of postage provided for in Section 1103, Act of October 3, 1917, authorized on August 3, 1918. Printed in U. S. A.

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Improvements in Ferro-Alloy Electric Furnaces of High Power Input

BY B. D. SAKLATWALLA and A. N. ANDERSON

Both of the Vanadium Corporation of America, Bridgeville, Pa.

Review of the Subject.—*The paper deals with the subject of efficiency of power input in ferro-alloy furnaces and discusses the electrical factors to be considered in the design of the leads for achieving such efficiency. It also describes a new system of regulation, whereby the furnace temperature is kept constant by keeping the energy input constant by means of true watt regulation. Also several factors in design and construction, are discussed, which help to keep the load-factor of the operation as close to 100 per cent as possible.*

* * * * *

ALL metallurgical furnace operations can be divided into two general classes, the one consisting of reducing ores by means of a reducing agent, commonly carbon, and the other consisting of remelting and refining already reduced metals. The electric furnace has been adapted to both classes of operations. To the latter class belong the steel and brass, and to the former the ferro-alloy furnaces. As the heat energy required for reduction of ores is much greater than that required for the mere melting and refining of metals the ferro-alloy furnaces are fed by comparatively very much larger amounts of power. Consequently, the structure and arrangement of these furnaces have presented more interesting problems from the standpoint of the electrical engineer.

Since the classical experiments of Moissan more than thirty years ago to reduce metals in the electric furnace the application of electrical energy has constantly widened in this field. The furnaces have not only been constructed for a constantly increasing number of products but also have increased in their size and power input, so that today furnaces having a 12,000 or even more kv-a. capacity are commercially operating. Undoubtedly in the United States the Niagara district can be called the cradle of this industry. It was there that the carborundum, aluminum, graphite, carbide, and ferro-alloy furnaces had their inception and commercially established by the efforts of such men as Hall, Acheson and Price, and from there with the development of power projects spread to other industrial locations.

In the early days little was known of the electrical phenomena met with in alternating currents of higher than 25-cycle frequency and little attention was given to the purely electrical phases of the problem. Practically the only consideration given was to have sufficient conductor cross-section for a predetermined current. The pressure to be employed was arbitrarily chosen. It was considered dangerous to go over 100 volts on a furnace. The control of the arc and of the bath resistance, and the spacing of the electrodes were considered not practical with high voltages. Generally the pressure decided on was between 40 and 80 volts.

Presented at the Spring Convention of the A. I. E. E., Pittsburgh, Pa., April 24-26, 1923.

As the size of the furnaces and their power inputs increased it was found that the conductors heated up excessively in spite of the fact that the current density was no greater than in the smaller initial installations. Addition of extra copper was helpful but did not effect a cure. The conductors insisted on heating up with a density as low as 400 amperes per square inch. Undoubtedly other factors had to be taken into consideration, especially as frequencies higher than 25-cycle had to be encountered. As 60-cycle current became more and more standardized it appeared for a time that furnace energy input at this frequency had reached its limit at 3000 kv-a. Meanwhile alternating-current phenomena were being studied and investigated by such men as Steinmetz, Northrup, Carson, Dwight, Roland, Rosa, Grover, and others, especially in reference to skin effect, spacing and shape of leads for heavy duty conductors. The theoretical considerations of skin effect had been studied mainly with reference to currents of high frequency, though undoubtedly this effect is present in heavy conductors carrying large currents at low frequencies. W. C. Kennedy in a paper presented before the Association of Iron and Steel Electrical Engineers in 1917 stated that the resistance loss due to skin effect on a 3750-kv-a., three-phase, furnace, at 12,000 amperes per phase, was by actual measurements about 11 volts per lead, the drop without skin effect being 0.15 volt for 10,000 amperes.

Numerous suggestions for cutting down impedance by methods of distribution of current, by proper spacing and dimensioning of bars, looping the circuit, so-called interlacing, etc., were forthcoming and eagerly investigated. Putting them into actual practise had, however, been deferred. It was, therefore, the desire of the authors to practically carry out these theoretical considerations in the design of ferro-alloy furnaces they were responsible for.

It appears to have been common practise for some time to employ tubular conductors for high-tension bus structures. However, they do not seem to have found use as conductors for large currents.

It appears to be generally accepted that the skin effect resistance factor of flat strip conductors is less than that of equi-sectional solid round conductors. This holds good only under certain conditions at com

mercial frequencies, the effect being influenced by the relative position of parallel conductors the current values of which are of opposite sign. Surveying all available data it indicated that copper tubes would have much less skin effect than equi-sectional conductors of any other form.

The ideal a-c. installation would have a total impedance equal to that of a d-c. installation of equi-sectional conductors. This would mean that the factors of skin effect, reactance and inductance in a-c. leads must be eliminated. As the elimination or neutralization of all these factors is very difficult, if not impossible, it follows that the best solution of the problem in a practical installation, would be the use of conductors of such shape, spacing and arrangement that the total impedance or a-c. resistance ratio to the d-c. resistance would approximate unity.

In the design under consideration, preliminary experiments from a metallurgical standpoint had proved the advisability of high voltages and also high-current density. As 220 was a standard pressure it was chosen. In order to secure high-current density, graphite was selected as electrode material and the size chosen was 12 in., the largest commercially available. Keeping the current density on the electrodes at about 100 amperes per square inch, ten to twelve thousand amperes could be obtained in each arc which for a three-phase three electrode equipment would represent a total energy of 4000 kw. This was adapted as a standard unit.

Since prevailing electric furnace practise was to use woven standard conductors or multiple straps in the endeavor to secure increased surface for a given carrying capacity of copper, and since this practise was found to result in considerable resistance loss in the conductors, also since many instances were found where no attempt had been made to investigate these phenomena it was thought that an effort to obtain the relation between factors influencing the passage of large current through such conductors might point the way to better practise.

Accordingly, a current density of 800 amperes per square inch of copper section was decided on with conductors 40 feet long. It was decided to investigate mathematically 8 different types of secondary transformer lead construction. These methods together with the tabulated results are shown in Table 1. The first three columns show different arrangements of 4 in. by 1/8 in. copper strips; fourth column an arrangement of 5 in. diam. copper tubes; the fifth and sixth columns 4½ in. diam. copper tubes; the seventh and eighth 3 in. copper tubes interlaced.

The results thus obtained indicated two promising methods. The first being from column No. 3 consisting of 72 strips of 4 in. by 1/8 in. copper interlaced and spaced 1/8 in. apart. The second in column No. 8 consisting of 12 copper tubes of 3 in. diameter spaced 7 in. center to center. For the two systems considered, calculated values as tabulated indicate the ratio of the a-c. resistance to the d-c. resistance and the total line loss for the tubes to be practically ½ of that of the strips.

THEORETICAL ELECTRICAL CONDITIONS IN ELECTRODE LEADS OF VARIOUS TYPES FOR 4,000 KV-A. ELECTRIC FURNACE

Electrical Properties									Remarks Relative to Property
Size	24-4 × 1/8" per Phase Straps in Contact	24-4 × 1/8" per Phase Straps Spaced 1/8"	72-4 × 1/8" Total Interlaced 1/8"	2-5" Tubes per Phase	3-4½" Tubes per Phase	3-4½" Tubes per Phase	4-3" Tubes Interlaced	4-3" Tubes Interlaced	
Remarks Rel. Type	Middle Phase	Middle Phase	Phases Balanced	Middle Phase	Middle Phase	Phases Balanced	Phases Balanced	Phases Balanced	When unbalanced
D.C. Resistance	0.000,027.1 Ω	0.000,027	0.000,027.1	0.000,026.6	0.000,024.3	0.000,024.3	0.000,026.9	0.000,026.9 Ω	Phase 1 R:000,549 Ω
$\frac{R_{ac}}{R_{dc}}$	2.18	2.01	2.01	1.13	1.09	1.09	1.02	1.02	Phase 2 R Ω
A.C. Resistance	0.000,059 Ω	0.000,054,2	0.000,054,2	0.000,030,1	0.000,026.5	0.000,026.5	0.000,027.5	0.000,027.5 Ω	Phase 3 R:000,549 Ω
Inductance	0.000,013,8 H	0.000,013,4	0.000,001,3	0.000,013,4	0.000,012,3	0.000,012,3			Phase 1 X_L:000,318 Ω
Ind. Reactance	0.005,20 Ω	0.005,060	0.000,490	0.005,060	0.004,65	0.004,65			Phase 2 X_L Ω
									Phase 3 X_L:000,318 Ω
IR-Drop	0.59 V.	0.54	0.54	0.30	0.27	0.27	0.275	0.275 V.	
IX_L-Drop	52.0 V.	51.0	4.9	51.0	47.0	47.0	26.4	24.7 V.	
% IR-Drop	0.465 %	0.426	0.426	0.237	0.208	0.208	0.217	0.217 %	
% IX_L-Drop	41.0 %	39.8	3.85	39.8	36.5	36.5	20.8	19.5 %	at Unity Power Factor
% Volts Loss	8.5 %	8.0 %	0.6 %	7.8 %	6.5 %	6.5 %	2.3 %	2.0 %	Total Volts Lost
Watts Line Loss	3 × 5900 W.	3 × 5400	3 × 5400	3 × 3000	3 × 2700	3 × 2700	3 × 2750	3 × 2750 W.	on basis of $\frac{220}{\sqrt{3}}$ V. to
% Watts Loss	0.44 %	0.41 %	0.41 %	0.23 %	0.20 %	0.20 %	0.206 %	0.206 %	neutral
DATA									
No. Electrodes - 3 - Y-Connected, bath is neutral									
Transformer - 1 - 3 Phase, ∇ Connected									
Primary Voltage - 22,000									
Secondary Voltage - 220									
Amperes per Phase 10,000									
Kv-a. Rating 4,000									
Current Density in Electrode Leads - 800 Amp. per ▫″									
Frequency = 60 ~ Values calculated for Conductors 20 Ft. Long Each									

TABLE I

The reactance volt-drop for all of the systems was then calculated for varying power factors at full load and results plotted as shown in Fig. 1 for power factor-voltage loss. Here the 4 in. by 1/8 in. strip interlaced showed up to much better advantage than the others for power factors of less than 99 per cent. On the other hand, as a preliminary experimental 750-kw. furnace was found to operate at a power factor very close to unity, it was decided that the same precaution taken to insure a high power factor could be utilized for the 4000-kw. unit. Moreover, the indicated reactance volt-drop for the interlaced 3-in. tubes would serve as a protection in case of sudden heavy overloads or possible short circuits, which, probably on very rare occasions only, are balanced in a 3-phase, 3-electrode system — the greater the state of unbalance the greater being the drop in voltage.

To summarize the tabulated calculations it is found that:

1. The larger the cross-section of the conductor the larger the skin-effect. This effect is appreciable at frequencies of 60 cycles for conductors greater than ½ in. diameter.

2. Skin-effect is higher in straps than in tubes of equi-sectional area with subsequent higher power loss.

3. Distribution of the current over the sectional area of a conductor is not affected by the inductive disposition of the conductor, since the internal inductance is unaffected by the mutual inductances.

4. Inductive reactance may cause considerable voltage drop in the electrode leads.

5. The larger the diameter of the conductors the less the inductance.

6. The farther apart the conductors the larger the inductance.

7. When inductive reactance expressed as per cent reactance drop amounts to 20 per cent or more, the actual volts drop in the line increases rapidly with decreased power factor.

Considering these factors, namely, the calculated voltage drop and line loss, the probable advantage of a progressively increasing voltage drop with decreasing power factor, and the fact that a bus structure of large copper tubing gave promise of a simple and rugged construction, it was decided to install 12 copper tubes of 3 in. diameter, interlaced and spaced 7 in. center to center, fixing the current density at approximately 800 amperes per square inch.

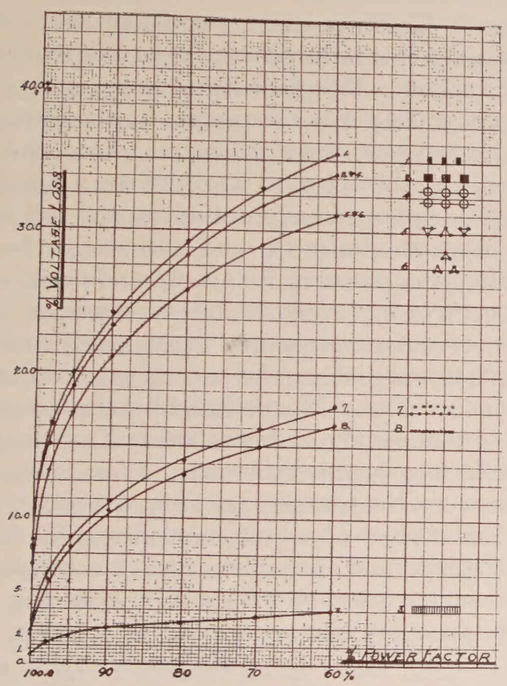

Fig. 1—Power Factor—Voltage Loss Curve for Various Types of Conductors

Next in order was to find a transformer so constructed that its secondary terminals could be brought out to allow the installation of the tubes as planned. The one purchased is wound with two secondary coils per phase, making four terminals per phase and the adjacent leads are brought out plus and minus. In the 12 terminals thus brought out the alternate plus and minus arrangement is continued over the series.

The transformer delivers a 4000-kv-a. output at 40 deg. cent. temperature rise and 5000-kv-a. at a rise of 55 deg. cent. It is water cooled, 3-phase, 60-cycle. The high-tension voltage is 22,000, low-tension, 224 volts at no-load which drops to 220 volts at full-load with 100 per cent power factor and 209 volts at a power factor of 90 per cent. The actual transformer impedance is 11.3 per cent.

The nearest approach to the tubular form of conductor for flexible leads for connecting the movable electrodes to the bus structure is the familiar asbestos cored extra flexible cable developed expressly for furnace operation. Consequently this type of cable of 1,000,000 circular mils diameter is used. There are 16 cables per phase, making 4 cables for each of the 3-in. tubes. The other end of the cable is connected to a 5-in. copper tube, about 8 feet long running across the furnace to the electrode holder. Directly underneath the terminals of the 3-in. tubes, which terminate at different lengths to allow placing of cables, are 3 slabs of slate each drilled with a hole just large enough to pass a cable. The 16 holes per phase thus drilled are in the form of a square, the spacing being such that each cable is 2 in. away from its neighbor. This spacing is maintained throughout the cable length by means of grooved blocks, one block clamping a row of 4 cables on both sides. These blocks also serve to prevent swaying motion of the cables without interfering with the up and down motion.

The general scheme of arrangement for adjacent tubes was applied to the cables. The "delta" connection is formed at the end of the 5-in. tube projecting over the back of the furnace and the cables are so placed that those carrying current of opposite sign are adjacent both with respect to cables in the same square and neighboring cables of adjacent squares.

This method of construction with respect to arrangement of the 3-in. transformer lead tubes and the flexible cables results in a very material reduction of impedance due to a-c. effects, as total resistance under full-load tests is increased but slightly over the measured d-c. resistance, the excess being less than 2 per cent with phases balanced. The absence of material reactive and inductive influences, and the absence of any iron forming magnetic fields in the circuit, naturally cause little if any disturbance in the phase relation between the impressed e.m.f. and the current, allowing the system to operate at a very high power factor.

Slight unbalancing of current values in the several leads does not materially affect the power factor. Heavy unbalancing however sets up impedances at which the power factor had been observed to drop below 0.6 and the voltage at the furnace, due to reactive inductance, drops approximately in accordance with the calculated power factor-voltage drop curve.

The phenomena of inductance and reactance are here utilized for the purpose of protecting the complete electrical equipment against heavy overloads, yet allowing it to operate at maximum efficiency when under control. It may be here pointed out that this effect could be further augmented by substituting for the 5-in. copper tubes over the furnace roof, a continuation of the interlacing system employed for the cables by extending the cables to the electrode holder, or by means of tubes or strips.

In order to control and keep up an electrical balance it is essential that the control mechanism employed be sensitive to slight changes in power and rapid restora-

tion of balance. Moreover, for this particular installation on account of metallurgical reasons it is necessary that the effective watt input to the furnace be controlled. Accordingly a control of this type was developed as shown in Fig. 2. The principal elements of the control consist of a watt measuring device and means for reversing rotation of motors to operate the electrodes. The watt element selected is that on the principle of the well known "Kelvin Balance" in which the movable or floating element coils receive the impressed e.m.f. of the circuit and the fixed coils a current proportional to that in the conductors. Each phase is regulated by its own watt element. The fixed coils are fed from a current transformer on the high-tension side corresponding to its low-tension component. The movable potential coils receive their energy from the low-tension side of

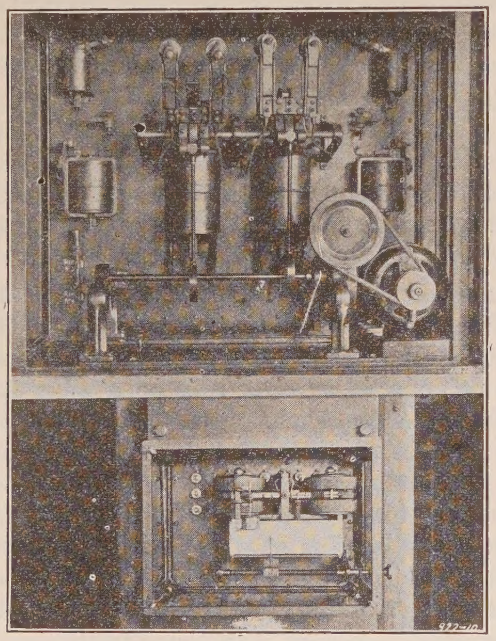

Fig. 2

the phase to which they are connected. The circuits operating the reversing switches of the electrode motors are closed and opened by relay method. The movable coil beam is provided with two-way contact points placed one above the other connected to a circuit of very small amperage (0.02 ampere), taken direct from the low-tension lines, energizing magnets placed in the motor switch cabinet.

At a predetermined wattage, obtained by means of a spring calibrated against the pull exerted by the movable coils, the beam is floating in balance and out of contact. As soon as any watt fluctuation occurs the beam is inclined and makes contact with one of the two-way points, closing the circuit operating the relay magnet in the switch cabinet. The point at which the beam makes contact depends on whether the pull is exerted by the spring overcoming the magnetic pull, in event of under load or vice versa for overload. The actuated relay magnet in the switch cabinet closes a circuit energizing another larger coil containing a plunger which lifts contact arms into the path of other contact arms in constant to-and-fro rocking motion. The meeting of the contact arms closes the circuit operating the electrode motors. The motion of the non-racking arms is controlled by means of very fine adjustments which allow them to meet the rockers during the desired part of the arc described by them, the speed of the rockers at the same time being variable. The rocking arms also make and break contact of the circuit operating the coils energized from the watt balance, which eliminates unnecessary closing of circuits, which in turn very materially cuts down the wear on the contacts affected.

Further to facilitate quick regulation and restoration of balance in the furnace a "selective regulation" device is applied. This consists of a set of 2 plunger magnets and a lamp in series per phase, one terminal of each set is connected to its respective phase, the other terminal being connected to the furnace. The lamps serve as pilot lights visually indicating the relative resistance between electrodes and furnace bath. The plunger magnets, one each for the up and down side of the motor reversing switches are so arranged that a change in current values causes the plungers to change positions from a predetermined neutral point adjustable by means of weights. Magnetic field exerts an upward pull on one plunger and a downward pull on the other. When the furnace load is balanced and resistance under electrodes equal, the plungers are all in the neutral position. A disturbance of potential balance in the furnace between the bath and electrodes causes a corresponding unbalance in the magnet coils and one or the other magnet of each set allows its plunger to drop. The dropping plunger opens the watt balance relay circuit for the up or down switches, depending on the nature of the disturbance, rendering one or the other of all the motor switch sets inoperative. For example: Should the resistance under one of the electrodes suddenly drop it would cause an increase in the furnace load and set all of the switches to work to raise the electrodes, however, as the decreased potential between the bath and the particular electrode causing the trouble decreases the current in the magnet controlling downward motion of the electrode decreases and allows its plunger to drop thus opening the relay circuit, but as the other magnet in the same set does not pull its plunger down the upward motion of the electrode is left undisturbed and the electrode is raised to restore balance. At the same time the current in the other sets is increased and causes the respective plungers to be pulled down thereby opening the relay circuit controlling the upward motion of the electrodes. This renders the switches for raising electrodes inoperative except for the elec-

trode which caused the trouble. Reversed condition reverses the operation of the magnets. Thus when one of the electrodes is out of balance this device throws the other two electrodes out of circuit and holds them in position while the unbalanced electrode finds its adjustment thereby restoring operating condition in much quicker time. By means of these regulations the period of contact of the arms and duration of circuit closing on the motors can be regulated to a great degree of nicety avoiding unnecessary movement of electrodes and wear and tear on the regulating equipment.

The general arrangement of the electrical equipment consists of two incoming 3-wire, 3-phase 22,000-volt feeder lines, equipped with lightning arresters and choke coils, automatic oil switches opening on overload and reverse current. A set of disconnecting switches are placed on each side of the oil switches. The lines feed parallel into a common set of busses. Each furnace transformer is connected to the bus through disconnecting switches and automatic overload and no-voltage release oil switch. All high-tension conductors within the building are of copper tubing. The secondary leads of the transformer are equipped with a set of disconnecting switches operated by hand or motor for "deadening" the portion of equipment situated in the furnace room, leaving the transformer alive to furnish power for motor drive, etc. The control room, containing all instruments, regulators, relays, etc., is a totally enclosed compartment. All instruments are placed on pedestals and the regulators in cabinets. This allows ready and easy access to all parts of the wiring and facilitates repairs. The low-tension disconnecting switches are operated from the control room. Switches of the same phase are levered to a common shaft and these shafts extend through the wall to the control room.

Each furnace is equipped, beside the regulators, with graphic recording watt meter, watt hour meter, voltmeter, ammeter for each phase and power factor meter. All of the instruments for the first unit installed are of the recording type to facilitate the study of the operation. The control room also contains a frequency meter. The furnaces may be regulated automatically or by hand — remote control. All switching, except high and low-tension disconnecting switching, is by means of remote control. An automatic change-over switch is located directly under the control room. This switch serves to connect the main factory feeder lines with a "live" transformer. It automatically shifts from a dead to a live line. It is operated, when desirable, by remote hand control from the control room. A spare set of regulator switches is provided that may be used on either furnace as may be required. A small auxiliary control room is located in the furnace building. This room contains switches for raising and lowering electrodes, ammeters and voltmeters. It is installed for the convenience of the furnace operators to enable them to change electrodes quickly and other work connected with the operation. While using these switches the main control room is automatically cut out and the motor speed automatically doubled. All high-tension leads and equipment are contained in bus structure and partitioned off from the rest. One transformer is placed in a vault, the other is of the out-door type.

It is highly desirable that an electric furnace operation of this nature be made continuous with interuptions as few and short as possible. With this view in mind facilities for rapid change of furnaces and of electrodes have been provided. The furnaces are placed on a double set of rollers at right angles to each other, so that when the furnace needed relining it was rolled out of its position, then rolled aside and a spare one already lined rolled into its place. This method of change can be effected in less than two hours time.

For the same reason an electrode holder was designed

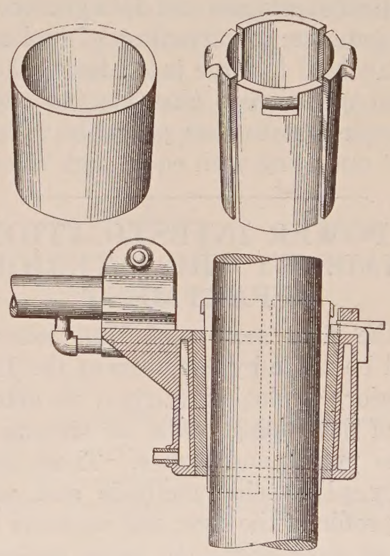

Fig. 3

to curtail the time of electrode changes. The holder used works on the friction-contact principle, eliminating all bolts, nuts or other tightening devices. It consists essentially of three members, (1) the outer casting of copper, forming a hollow water-cooled ring having a slight taper on the inside; (2) a copper ring fitting inside of the water-cooled ring and having its outside surface tapered to conform to the inside surface of the first member; (3) bronze wedges fitting between the second member and the electrode. In operation the second member is applied to the electrode by means of the wedges, this taking place on the furnace room floor and the electrode thus provided is lifted with the crane and simply dropped into the first member, making a friction contact by its own weight. The arrangement is shown in Fig. 3.

The advantage of this device, besides saving time, is that it obviates the necessity of loosening or tightening bolts or other devices on top of the furnace where working conditions are disagreeable. Further, should the holder get hot, as the water-cooled outer ring and electrode do not expand, the only material that can expand would be the second member ring and the wedges, which would produce a tighter contact, instead of a looser one, as in the case of a holder of the ordinary type. Also, as the electrodes are prepared for service between changes, under agreeable working conditions and at more leisure, it follows that, in preparing the wedges and ring they are properly cleaned and adjusted, insuring good contacts. This holder permits the change of an electrode in 1 to 2 minutes.

This furnace equipment operates at an average power factor of 99 per cent and an over-all electrical efficiency — for transformer and low-tension leads to electrode —of 98.5 per cent. Repeated tests in operation check well with calculated values.

The practical experience and data gathered from this installation indicates the advantage of application of the principles involved to large input furnaces for various metallurgical operations. Also they indicate the feasibility of larger installations probably with twice the power input operating with equal high efficiencies.

WATER POWER INVESTIGATION TO BE MADE BY THE INTERIOR DEPARTMENT

During the field season of 1923 extensive river surveys will be made by engineers of the Department of the Interior, Geological Survey, to determine the possibility of developing power on streams in practically all the public-land States. These surveys will be made by plane-table methods and will include a plan and profile of the river and contours to a height of 200 feet or more above the water surface. Where the conditions are favorable to the construction of dams or reservoirs, special surveys will be made for mapping on a relatively large scale. Hydraulic engineers will select the dam sites and geologists will examine and report upon the geologic features of those that appear to be the most favorable.

These surveys and the records of stream flow collected by the Geological Survey form the basis for the classification of public lands with reference to their value as power sites. Most of the maps made will be published and will be available for purchase at moderate prices. Many of the reports prepared as a result of such surveys are published as water-supply papers or are kept open for public inspection at the district offices of the Geological Survey as well as at Washington D. C. A complete inventory of the water-power resources of the public-land States is thus being prepared. The program for 1923 includes the following work:

In Oregon 300 miles of Rogue River and tributaries will be mapped and surveys of dam sites will be made.

In northern California and Oregon, the surveys of Klamath River from Keno, Oreg., to its mouth will be completed. This work will involve 100 miles of additional surveys.

In Utah, surveys covering 100 miles will be made on East or Yellowstone Fork of Lake Creek, West Fork of Lake Creek, Rock Creek, Duchesne River, and Uinta River.

In Idaho, surveys of a dam and reservoir site will be made on Salmon River.

In Montana, a dam site on the South Fork of Flathead River will be surveyed and a reconnaissance will be made to determine the possibility of using Missouri River and its tributaries above Great Falls, Mont., for power purposes.

In Colorado, surveys will be made on South Boulder River, Clear Creek, Chicago Creek, St. Vrain Creek, Left Hand Creek, Big Thompson River, North St. Vrain Creek, South St. Vrain Creek, and Middle Boulder River, all tributaries of South Platte River.

In Wyoming, surveys will be made on Sweetwater, North Platte, and Encampment rivers.

In Arizona and Nevada, 300 miles of Colorado River will be mapped.

In Washington, investigations of the Columbia Basin irrigation project are now being made.

Public lands reserved for use in connection with power sites and shown by these surveys to be without power value will be recommended for restoration to entry. Lands that may be used in connection with power sites but that are well adapted to other uses will be recommended for restoration to entry with a reservation of the right of the United States or its permittees to use them as power sites. Public lands that are found to be valuable as power sites and that are not already reserved will be classified as power-site lands and withdrawn from entry.

WATER POWER INVESTIGATION

LEAD RESISTANCE IN CURRENT-TRANSFORMER TESTS

In the accurate use of current transformers, such as are used for the measurements of large amounts of power supplied at high voltage, it is very essential that the transformers be tested when connected to a secondary circuit which is identical with or equivalent to the circuit with which they are used. The apparatus by which such devices are tested in standardizing laboratories such as that of the Bureau of Standards, necessitates the introduction of a certain amount of resistance into the circuit. If the circuit with which the transformer is to be used contains a lead resistance of as much as one-tenth ohm, it is quite feasible to substitute the testing apparatus for these leads when the transformer is tested. In case, however, the leads used with the transformer have much less resistance, it becomes impracticable to make the calibration under precisely the same conditions as those under which the transformers are used.

Voltages Induced by Arcing Grounds

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THE subject of arcing grounds in transmission systems is one of the greatest interest to operators of power systems of any extent. The almost universal grounding of the neutral in this country is done primarily to alleviate the destructive effects produced by arcing grounds. However, in spite of its great importance, a clear understanding of what happens in an arcing ground in not general. There is no agreement as to the magnitudes of voltages and surges produced, and the various theories proposed call for different properties of the arc. The authors therefore considered it well worth while to attempt in the laboratory to duplicate the conditions of an arcing ground on a transmission system and by spark gap determinations of voltages and by oscillograms to determine the maximum voltages developed and to discriminate between the various theories proposed.

Transient Conditions in Electrical Systems

Any sudden change in the constants in an electrical system in general produces transient oscillations which superimpose themselves upon the normal voltage and current distributions in the system. A simple example may be given in the closing of a switch in a circuit containing inductance and capacity in series, such as is indicated in Fig. 1A. Fig. 1B shows the manner in which the condenser acquires the voltage of the power supply, the battery. The voltage on the condenser does not at once come to that of the battery but there is a transient oscillation about this voltage provided the resistance in the circuit is not too great. The initial amplitude of the oscillation will be equal to the change in voltage which the condenser must undergo in passing from its initial condition to the final steady condition. Therefore, in Fig. 1B the maximum voltage which the condenser momentarily takes on is approximately twice the voltage of the supply.

In respect to the effect upon the insulation of electrical apparatus two factors must be considered in these transient oscillations. One is the absolute value of the potential reached in the oscillation and the other is the rapidity or steepness with which the potential changes during the transient condition. The latter factor plays an important part in determining the distribution of potentials within the apparatus during the transient condition, whereas the former determines the stress upon the insulation to ground. In transmission systems rapidly changing or steep wave front surges are impressed upon the apparatus as a result of the distributed character of the inductance and capacity as will be explained in more detail later in the paper. The type of oscillation considered in the first part of the paper, which will deal entirely with lumped inductances and capacitances, will involve changes of potential which are so slow that practically only the absolute value to ground will be important.

It is obvious that an arc when it starts constitutes just such a sudden change in the constants of a circuit

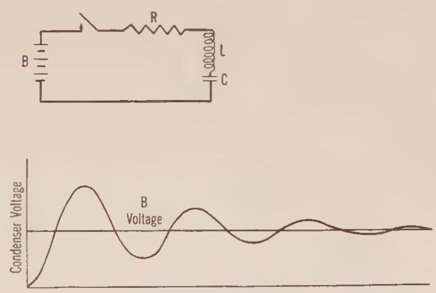


FIG. 1—SIMPLE OSCILLATING CIRCUIT

as has just been described so that when it strikes, an arcing ground must necessarily set up oscillations similar to those set up by closing a switch. However, there is a concensus of opinion that an arcing ground has in it more elements of danger than would correspond merely to this effect. It is generally believed that short-circuiting a line permanently to ground will not produce nearly the same disastrous results as arcing grounds are known to do.

Theories of the Arcing Ground

Three theories to explain the high voltages induced by arcing grounds have been proposed. To explain these three theories in a similar manner the authors prefer to describe the action going on in an arc by an artifice of properly manipulated switches. The resistance of an arc is not a constant quantity but may vary from a practically infinite value when the current through it is very small, to an almost zero value when the current

Presented at the Spring Convention of the A. I. E. E., Pittsburgh, Pa., April 24-26, 1923.

through it is very large. Thus when alternating or pulsating currents traverse the arc the resistance of the arc may undergo changes which may keep pace with these pulsations or alternations of current. A switch also may be made to vary the resistance in a circuit from very high to very low values. The three theories may be classified according to how the change of resistance of the arc from low to high values or vice versa or the equivalent switching is controlled.

Theory I. Switching Controlled by the High-Frequency Oscillation

This is usually known as the theory of generation of high-frequency by the "negative resistance" of the arc. The Poulsen arc generator of radio frequency currents operates on this principle. The manner in which oscillations are built up when a switch is operated synchronously with the natural period of an oscillating circuit which it shunts may be seen from Fig. 2. Fig. 2A shows the circuit diagrammatically and Fig. 2B shows the building up of voltage on the condenser as the switch is operated. Beginning with the switch open, the condenser C is charged to the voltage of battery B with zero current flowing through the inductance L and resistance R. On closing the switch the condenser begins to discharge through the inductance giving an oscillation, such as has just been described, about the zero voltage value to which the condenser would ultimately come if the switch remained closed. However, suppose at the end of a half cycle of this oscillation at the moment the current from the condenser is zero, the switch is opened. At this moment the condenser has a negative voltage equal in magnitude to the positive voltage which was first impressed upon it. An oscillation then begins in the circuit consisting of the condenser, inductance, resistance and battery. At the start of this oscillation the voltage of the condenser will add to the voltage of the battery in building up current through the inductance L and the resistance R. If the switch were left permanently open after the transient oscillation, the condenser would again come to have the voltage of the battery B. The amplitude of the oscillation will therefore, as Fig. 2B shows, be equal to twice the battery voltage so that the maximum potential which the condenser attains will be after the first half cycle of this oscillation equal to three times the battery voltage.

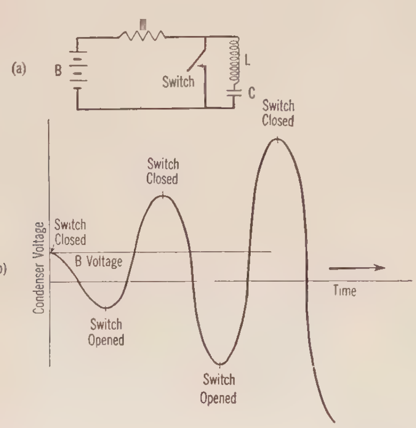


Fig. 2—Generation of Oscillations by Synchronous Switch

Now suppose at this moment the switch is again closed. The condenser, charged to three times battery voltage, again undergoes an oscillation and after a half cycle has a negative voltage three times that of the battery. We may again suppose the switch opened.

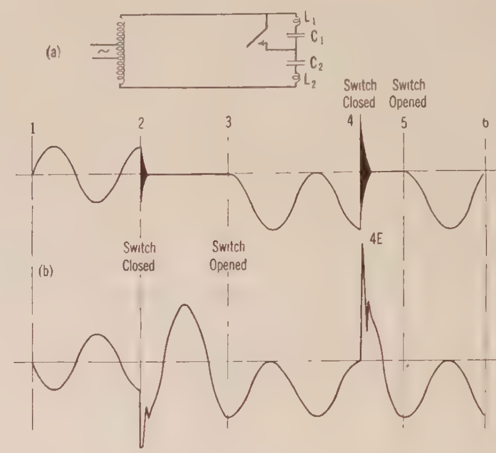


Fig. 3—Switching Controlled by 60-Cycle Conditions in Single-Phase Circuit

The oscillation which then takes place in a half cycle will bring the condenser to a positive voltage of five times that of the battery. In this way the voltage on the condenser may build up to indefinitely large values.

Of course the resistance of an actual arc may not range from zero to infinite values. A closer approximation to the action of an arc building up oscillations, due to its "negative resistance" characteristic may be obtained by using one or more switches shunted by and in series with properly chosen resistances.

To apply this theory to an arcing ground on a transmission system, Fig. 3A will more nearly represent actual conditions. The oscillating circuit will then be the inductance and the capacitance of the grounded phase, L_1 and C_1, or the inductance of the generating system and the inductances and capacitances, L_2 and C_2, of the ungrounded phases, or both.

Theory II. Switching Controlled by 60-Cycle Conditions

Again using Fig. 3 we may follow the oscillations and the resultant development of potentials which ensue when the changes in the resistance of the arc or the opening and closing of the equivalent switch are controlled entirely by 60-cycle conditions. Let us suppose that the striking of the arc or closing of the switch takes at the moment when the 60-cycle voltage across it is a maximum and that the extinction of the arc or opening of the switch takes place when the 60-cycle current

through it is passing through zero. Assume that the two capacitances in Fig. 3A are equal or that a single-phase transmission line is being considered. Just before the first closing of the switch the voltages on the condensers will be as shown in portion 1-2, in Fig. 3B. Now, when the arc strikes or the switch closes at 2, L_1 C_1 undergoes a rapidly damped oscillation, damped because we are supposing that the resistance of the arc does not follow or synchronize with this high-frequency oscillation. C_2 L_2, together with the inductance of the supply system, will undergo a somewhat lower frequency oscillation, but also damped. The maximum potential reached by C_2 during this oscillation will be three times normal voltage while the maximum voltage reached by C_1 will be nearly equal to normal voltage. When the effects of these oscillations have completely disappeared the voltage on C_1 will remain zero, while the voltage on C_2 will be 60 cycles and double its former value and equal to that impressed by the generating system. This condition of affairs is shown in portion 2-3, in Fig. 3B.

The current through the arc or closed switch is now the charging current of the condenser C_2. It will, therefore, be zero at the moment when the voltage on C_2 is a maximum. Let us suppose, then, that at such a moment the arc extinguishes or that the switch is opened. Opening the switch at this point evidently leaves a charge trapped on the condensers. From this point on the variation in supply voltage will again divide equally between the condensers. The course of of these voltages will then be as shown in portion 3-4, Fig. 3B; the charge which is retained upon the condensers causes their respective voltage waves to be displaced from the former zero line by an amount equal to their normal voltage.

If the leakage of the condensers is small this condition will persist until the arc strikes or the switch closes for its second time. Again we assume that this closing of

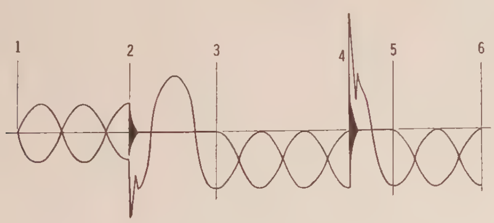


Fig. 4—Curves of Fig. 3 Referred to Common Zero

the switch takes place at the maximum of the voltage wave. Immediately after the striking of the arc transient oscillations take place, as shown at 4, in Fig. 3B, just as took place at 2. However, it is obvious that now the amplitude of oscillation of C_2 will be twice as great as that at 2 so that the maximum voltage reached will be four times normal voltage. The maximum voltage reached by C_1 will be twice normal voltage. Now if we suppose the switch stays closed so that these oscillations completely damp out we will again be back in the condition shown in portion 2-3. Again, during the period 4-5, the voltage on C_1 will remain zero and that on C_2 will be 60-cycle and of double normal value. Again the arc will extinguish or the switch will open when the 60-cycle current through it is zero, which will be at a maximum of the voltage wave of C_2, as shown at 5. When the switch does open we will then be exactly in the condition as shown at 3 so that should the arc strike again an oscillation will again take place exactly as shown at 4 with the development again of voltage four times normal on C_2 and twice normal on C_1. Thus, however often the arc may restrike and re-

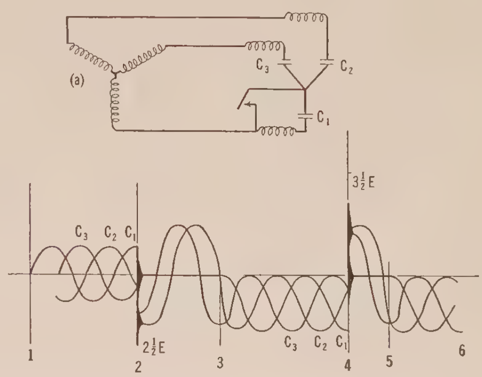


Fig. 5—Switching Controlled by 60-Cycle Conditions in Three-Phase Circuit

extinguish, conditions will not become any worse than that shown at 4.

To follow conditions more clearly in the three-phase case, which will now be considered, it is desirable to combine the two curves of Fig. 3B upon a common zero line as shown in Fig. 4. Studying the curve of Fig. 4 we see that during the periods when the arc is extinguished, 1-2, 3-4, 5-6, the two curves preserve an invariable relation to each other but that after the extinction of the arc 3-4, 5-6 are displaced so that they become tangent to the normal zero line. During the periods that the arc is on 2-3, 4-5, one of the condensers, except for the transient oscillations, has a zero voltage. The amplitude of the oscillation which takes place upon each striking of the arc is equal to the change in voltage which the condensers must respectively undergo in passing from the steady condition before the striking of the arc to the steady condition after the striking of the arc.

Being guided by Fig. 4, we may now readily draw the course of voltages under this theory for the case of a three-phase transmission system. Fig. 5A is the diagram of the three-phase circuit and 5B shows the voltages on the condensers. Before the striking of the arc in the portion 1-2 of Fig. 5B the three voltage waves are in three-phase relation and symmetrical about the zero line. After the first striking of the arc and after the initial oscillations have died down, just as in Fig. 4, one of the voltages will be reduced to zero while the other two will take delta voltage symmetrical about

the zero line. This is shown in portion 2-3. When the arc extinguishes the three voltage waves will will have the same position relative to each other as they had in the portion 1-2 but will now be displaced so that they are tangent to the zero line. After the arc extinction again at 4 and after the oscillations have damped out one of the voltages will again be zero and the other two will be delta voltages about the zero line. After the extinction of the arc at 5 the voltages will be relative to each other again as in portion 1-2, but again will be displaced so as to be tangent to the zero line as in 3-4. The steady conditions of voltage before and after the striking of the arc being known, the amplitudes of the oscillations are readily determined. The amplitude will, of course, be equal to the amount by which the voltage on any one condenser must change to get from the value it had in the steady state it was leaving to the value it will have in the steady state it is reaching.

At the moment 2 in Fig. 5, condensers C_2 and C_3, just before the striking of the arc, have the voltage $\frac{1}{2} E$, where E is the normal voltage to neutral. After the arc has been on long enough for steady conditions to be reached the voltage will be $1\frac{1}{2}$ times normal voltage to neutral. The amplitude of the oscillation which takes place in going from the one condition to the other will therefore be equal to the difference of $1\frac{1}{2} E$ and $\frac{1}{2} E$, or equal to E. Hence, it is obvious that the maximum of voltage reached by the condensers C_2 and C_3 will be $2\frac{1}{2}$ times E.

Upon the second striking of the arc at 4, conditions are different because of the fact that the voltage waves are displaced in the portion 3-4. Here, before the striking of the arc, the voltage to ground of the condensers C_2 and C_3 will be $-\frac{1}{2} E$. After the arc has been on long enough for conditions to become steady the voltage of condensers C_2 and C_3 will have become $+1\frac{1}{2}$ times E. The amplitude of the intervening oscillation, therefore, will be equal to 2 times E, so that the maximum voltage reached by the condensers C_2 and C_3 will be $3\frac{1}{2} E$.

From this point on, conditions will repeat with the development of no higher voltages. Inspection of 5B shows that the maximum voltages reached by the short-circuited condenser C_1 will be equal to E on the first striking of the arc at 2, and $2 E$ on subsequent strikings, as at 4.

Theory III. Switch Closing Controlled by 60 Cycles and Opening by High Frequency

This is a theory which has been advanced and elaborated by Petersen[1] in recent years. This theory assumes that the arc strikes at or near the maximum of the 60-cycle voltage wave but that the arc extinguishes at a moment when the arc current passes through zero as a result of that high-frequency oscillation which is of intermediate frequency.

Referring to Fig. 6, we may follow the development of voltages consequent upon this hypothesis. Again considering the equivalent of a single-phase line with equal condensers C_1 and C_2, we have before the striking of the arc equal voltages symmetrical about the zero line in the portion 1-2 of Fig. 6B. The arc is then supposed to strike at 2 when the voltages are maximum. The short-circuited condenser undergoes a damped oscillation of high frequency. The other condenser begins an oscillation which will be of lower frequency because it includes the inductance of the generating system. The initial amplitude of this oscillation is evidently equal to E, the normal voltage to neutral. The current through the arc corresponding to this oscillation will be zero when the voltage of this oscillation reaches its maximum and at this point 3 the arc is assumed to extinguish or the switch to open.

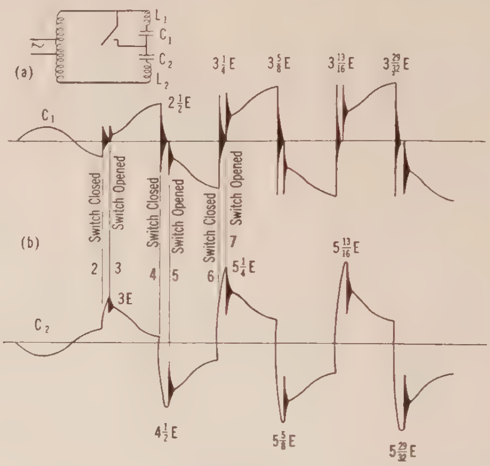


Fig. 6—Switching Controlled by High-Frequency Conditions

The voltage on condenser C_2 at this moment is 3 times E, whereas that on condenser C_1 is zero. The supply voltage, however, can only maintain a difference of potential of $2 E$ between the condensers C_1 and C_2. There is, therefore, an equalization of charge between the condensers C_1 and C_2 until the voltages on C_1 and C_2 come to differ by $2E$. Thus there is at 3 a charge equalizing oscillation and after this is damped out the voltages of C_1 and C_2 are, respectively, $+\frac{1}{2} E$ and $+2\frac{1}{2} E$. The arc being extinguished, the course of voltage change of the two condensers C_1 and C_2 is as it was before in portion 1-2 except that they are displaced from the zero line.

We now suppose that the next striking of the arc or closing of the switch takes place when condenser C_1 reaches its maximum voltage to ground. This will be one-half cycle later at 4 in Fig. 6B when the voltage of C_1 will be $+2\frac{1}{2} E$ and that of C_2, $+\frac{1}{2} E$. The arc strikes; condenser C_1 loses its charge completely in a rapidly damped high-frequency oscillation and condenser

1. E. T. Z. 38 Heft 47, Nov. 22, 1917, pp. 553-555.
E. T. Z. 38 Heft 48, Nov. 29, 1917, pp. 564-566.

C_2 begins a lower frequency oscillation. The steady state value of voltage to which condenser C_2 strives at this point is $-2\ E$. The voltage which it has at the moment it starts the oscillation is $+\frac{1}{2}\ E$. The amplitude of the oscillation is the difference between these two values, or $2\frac{1}{2}\ E$. The maximum of voltage which it reaches, therefore, will evidently be $4\frac{1}{2}\ E$. At the moment it reaches this maximum voltage by the hypothesis as to the nature of the arc, the arc extinguishes or the equivalent switch is opened. Again there is an oscillation which equalizes the charge upon the two condensers. Since one condenser must rise in voltage through this equalizing oscillation by the same amount that the other condenser falls in voltage and since 60-cycle equilibrium will be obtained when the two condensers differ in voltage by $2\ E$, it is evident that after the equalization of charge the voltages of C_1 and C_2 will be respectively $-1\frac{1}{4}\ E$ and $-3\frac{1}{4}\ E$.

We may repeat this process at succeeding half cycles. The series of maximum voltages reached by C_2 will be $5\frac{1}{4}\ E$, $-5\frac{5}{8}\ E$, $+5^{13}/_{16}\ E$, etc., evidently approaching $6\ E$ as a limit. The maximum voltages on C_1 in a similar manner approach the value $4\ E$ as a limit.

If the condensers are not equal but in the ratio n, $C_2 = n\ C_1$, the limiting maximum voltages will be $(4n + 2)\ E$, for C_2, and $4\ n\ E$ for C_1, where $2\ E$ is the voltage of the supply system. For the three-phase case, with three equal capacitances, the limiting maximum voltages figure out as $7.5\ E$ for the ungrounded phases and $6\ E$ for the grounded phase, where E is normal voltage to neutral.

In the discussion given here in Theory III, it has been assumed that there is no leakage in the condensers. If such leakage exists it is evident that it will operate to limit the voltages reached.

Properties of Arc Required by the Three Theories

The three theories discussed are all similar in depending upon the property of an arc of undergoing large changes in resistance under various circumstances. The theories differ in their hypothesis as to what these circumstances are. It seems desirable, then, to examine the three theories critically in the light of what is generally known of the properties of arcs in the air.

The familiar volt-ampere characteristic of an arc is given in Fig. 7. Interpreting in terms of resistance the figure states that the resistance of the arc is large for small values of the current and small for large values of the current. This seems to be exactly the characteristic required by Theory 1, for in the discussion of Theory 1 the open switch or high resistance was introduced in the circuit at the time the current from the condenser was opposing the power current through the switch, whereas the switch was closed or low resistance introduced when the current from the condenser was adding to the power current through the switch. However, the curve of Fig. 7 is the relation obtained between volts and amperes of an arc when the current through it varies only slowly. If the current in the arc is varied rapidly quite different characteristics may be obtained. As an illustration of the change in the characteristic of an arc when the current is varied rapidly we may refer to Fig. 8, taken from "Fleming Electric Wave Telegraphy & Telephony," 3d edition, 1916. The striking contrast between Fig. 8B and Fig. 7 indicates that it is not permissible to assume that high frequency can be sus-

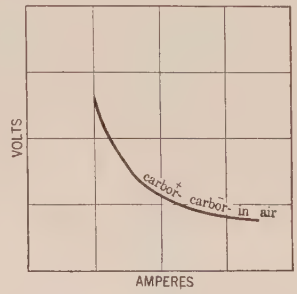


Fig. 7—Static Characteristic of Arc in Air

tained by an arc because it has a static characteristic such as Fig. 7. In fact, in order to sustain high frequency by means of arcs it has been found necessary, as in the Poulsen arc radio frequency generator, to adopt measures to prevent the altering of the static characteristic such as by the use of powerful magnetic fields and of special gases. Fig. 8A, for example, shows a 60-cycle arc between carbon electrodes in coal gas and gives a characteristic more nearly like that of the static

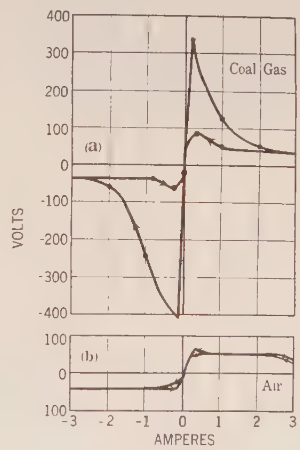


Fig. 8A—Dynamic Characteristic of Arc in Coal Gas
Fig. 8B—Dynamic Characteristic of Arc in Air

characteristic of Fig. 7. These considerations rather remove the possibility of Theory 1 of the development of high voltage by an arc.

Theory III suffers under a similar difficulty in requiring a property of an arc which is attained only when special methods or measures are taken. In Fig. 8B, for example, when the current passes through zero rapidly the voltage necessary to reignite the arc is only of the order of 40 or 50 volts, so that it is hardly likely that an

arc in air will extinguish when a current of the order of a few amperes is passing through zero at a rate corresponding to a thousand cycles or more. The second hypothesis, therefore, of Theory III, which requires the arc to extinguish on the first passing through zero does not seem to be well founded on the actual properties of arcs.

Theory II would seem to have the best substantiation in the known properties of arcs. The arc, if it strikes at all, will of course be most likely to strike at the peak of a voltage wave. Again the arc, if it goes out at all, will go out as the current is passing through zero and the current will be passing through zero with the least rapidity and therefore with the closest approach to the static characteristic when it is the 60-cycle or lowest frequency current.

Experimental Work

Apparatus: A photograph of the assembled apparatus used in these experiments is shown in Fig. 9. The transformer used as a supply was 250 kv-a., single-phase,

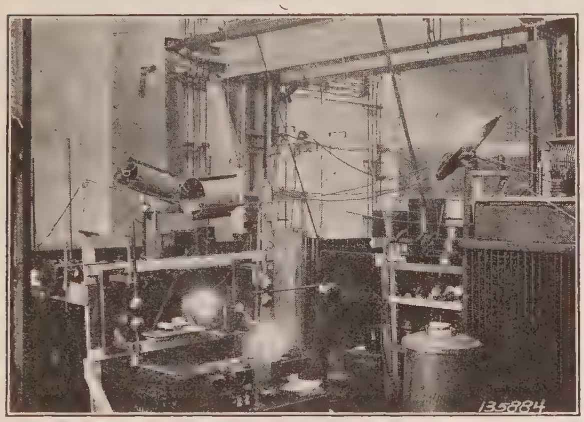


Fig. 9—Set-Up of Test Equipment

2200-13,200 volt, 60-cycle. A 228-millihenry air cored reactance was arranged in the primary side of the transformer so that it could be short-circuited or left in, as desired. Various air cored reactors were used in the high-voltage side and values are tabulated in the experimental results. The condensers consisted of four units each of 0.2 microfarads and were capable of withstanding 100,000 volts. They were made up of fullerboard in oil as the dielectric with sheet iron for plates.

Condenser bushings were also used where smaller values of capacitance were desired. The spark gaps for measuring the voltage developed were 12½ cm. sphere gaps. The gap used for producing the arc is shown in Fig. 10.

The lower electrode was provided with a screw to change the length of the gap and could be operated from a distance by means of a string. The upper electrode was on a swinging arm which could be moved by means of an insulating rod. A pipe connecting with the compressed air supply was brought up bearing on the gap so that the arc could be subjected to an air blast at will.

In order to take oscillograms without disturbing the voltage conditions it was necessary to adopt special measures to reduce the current required by the oscillograph to a negligible value. This was done by the use of three electrode vacuum tubes. A diagram of connections is shown in Fig. 11. The tubes were experi-

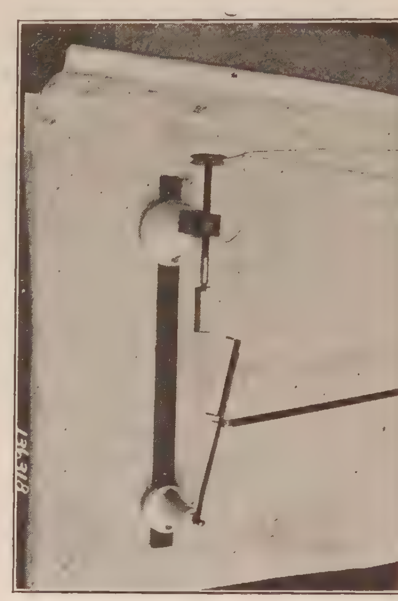


Fig. 10—Switch Used for Striking Arc in Tests

mental 50-watt radio transmitting tubes and were used with plate voltages from 750 to 900 volts. The plate current under these conditions was about 0.1 amperes. The resistors R_1 and R_2 were tubes of distilled water which were frequently measured and varied from 4.5 to 8.8 megohms. The resistors r_1 and r_2 were wire wound resistors of relatively low values. No effort was

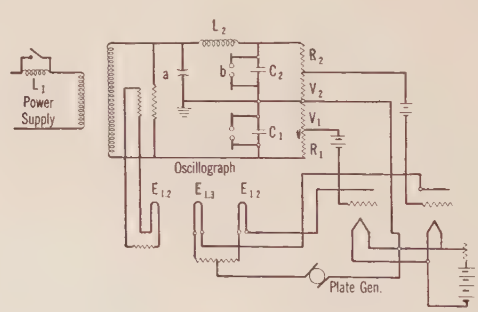


Fig. 11—Connection Diagram of Oscillographic Tests

made to eliminate slow time changes in the values of the water resistances.

Experiments to Determine the Influence of the Metal in Arc Electrodes

First experiments were undertaken to determine whether the nature of the metal making up the elec-

TABLE I

	Iron and alum.	Copper and iron	Copper and copper	Copper and alum.	Brass and brass	Brass and iron	Remarks
Volts at b	10,000	10,300	9500	8500	9400	11,000	Without air blast
Volts at c	23,400	24,200	23,000	22,000	..	..	Without air blast
Volts at b	11,500	11,500	11,000	11,000	..	..	With air blast
Volts at c	23,500	24,500	24,900	24,700	..	..	With air blast
With C_1 of Circuit above short-circuited							
Volts at b	22,500	23,200	21,200	22,500	..	..	Without air blast
Volts at b	28,800	29,500	33,000	30,500	..	..	With air blast

During the above tests voltages were measured as follows:

E_{sec} with voltage transformer = 12,960
E_b with gap b = 7700
E_c with gap c = 7050

trodes of the arc played any particular part in the magnitudes of the voltages developed.

Fig. 12 gives the diagram of the circuit and Table I gives the results obtained on these tests. In these tests the upper electrode of the arc gap was kept stationary and the gap drawn out by rotating the threaded lower electrode. The table clearly shows that the metals making up the arc electrodes had no great influence

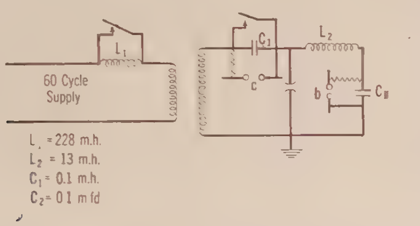


Fig. 12—Connections Used in Testing Effect of Different Electrode Materials

upon the voltages developed and therefor in the subsequent tests only copper electrodes were used.

Experiments to Determine Voltages Developed in Arcing Ground

The circuits used are shown in Fig. 13 and the results are given in Table II. During the progress of this work various oscillograms were taken of which characteristic ones will be given and described in the discussion of results following.

Discussion of Experimental Results

The table of voltages observed under various conditions given above may be checked against the voltages which the three theories would require to be developed on the condensers.

Theory I permits the development of practically unlimited voltages upon the condenser in the oscillating circuits. Theory II, however, if the condensers are equal, limits the maximum voltage which can be obtained on the short-circuited condenser to twice its normal voltage and the maximum voltage which can be obtained on the other condenser to four times its normal voltage. When the short-circuited condenser is much smaller than the other, Theory II limits the voltage which can be developed in it to twice its normal voltage, or, that is, twice the voltage of the supply and the voltage of the other condenser to three times the voltage of the supply. Theory III, for the case of equal condensers, will permit the development of four times normal voltage on the short-circuited condenser and six times normal voltage on the other condenser. If the short-circuited condenser is small compared to the other, then Theory III permits of practically unlimited voltages.

Examining Table II we find that the results are entirely in agreement with the predictions of Theory II.

In the case of equal condensers, as shown in tests 1-20 and 76-90, inclusive, with the exception of the first four tests, no voltages exceeding twice normal or 13,000 were observed on the short-circuited condenser; although voltages were observed exceeding this value, all the voltages were nearly equal to this value. For the voltage across the other condenser in no tests was more than three times normal voltage observed and in many cases this value three times voltage was nearly reached. The falling short of the maximum values predicted by the theory is to be expected because of the leakage from

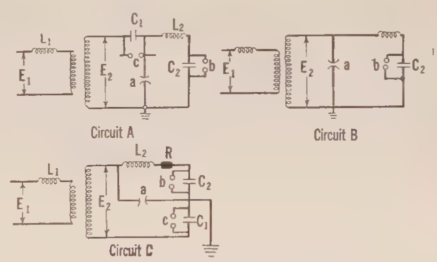


Fig. 13—Connections Used in Arcing Ground Tests

the condensers during the relative long time between successive drawings of the arc.

Unequal condensers were used in tests 30-44 and 51-63. The unlimited voltages called for by Theories I and III were not observed at all and even the maximum voltage of three times the supply voltage required by Theory II was not observed. However, more than twice supply voltage was usually observed and the smallness of the condenser with the attended rapid leakage of charge between strikings of arc readily explains the inability to obtain higher voltages.

TABLE II

Test	Circuit	C_1 μf	C_2 μf	L_2 mh.	L_1 mh.	E_1 volts	E_2 volts	E_b volts	E_c volts	Kind of arc	b in volts	c in volts	Film No.	Remarks
1	*A*	0.1	0.1	13	228	..	12,960	6500	6400		16,900	22,500	..	The min. length of gap *a* = 1/8″
2	"	"	"	"	"	..	"	"	"	Air	19,000	25,500	..	" " " " " " " "
3	"	"	"	"	"	..	"	"	"		14,800	25,500	..	" " " " " " " 3/16″
4	"	"	"	"	"	..	"	"	"	Air	15,000	25,000	..	" " " " " " " "
5	"	"	"	"	0	..		..	..		11,600	22,800	..	No *R* across C_1 & C_2 for making oscillograms
6	"	"	"	"	"	..		..	..		11,300	21,000	..	With *R* across C_1 & C_2 (see sketch for oscillograms)
7	*C*	"	"	"	228	2300	..	6800	7100		11,800	24,200	..	No *R* across C_1 & C_2 (checking change in circuit for taking oscillograms)
8	"	"	"	"	0	..	..	..	..		11,500	20,000	..	
9	"	"	"	"	"	..	..	..	..		11,400	21,000	72,579-a, b, c & d	
10	"	"	"	"	"	..	..	..	..		..	..	72,579-e	
11	"	"	"	"	"	..	..	..	..	Air	..	..	72,579-f	
12	*A*	"	"	"	"	..	13,130	..	..		12,500	..	..	
13	"	"	"	"	"	..	"	..	..	Air	12,000	21,000	..	
14	"	"	"	"	"	..	"	..	..	Air	..	19,600	..	
15	*C*	"	"	"	"	..	..	..	..	Air	..	..	72,579-z	
16	"	"	"	"	"	..	..	..	..	Air	..	..	72,579-h	Thin pointed electrodes at *a*
17	"	"	"	"	"	..	..	..	..	Air	..	..	72,579-i	One tube out. Object to check regulation of plate generator.
18	..	..	..	..	..	..	..	..	..	Open circuit voltage of transformer			72,579-j	Object: to find cause of h. f. ripple in wave supply voltage.
19	*C*	0.1	0.1	13	0	..	13,440	5850	5600		10,400	19,800	..	To check conditions before making oscillograms.
20	"	"	"	"	"	..	..	..	..	Air	10,500	19,100	..	To check conditions before making oscillograms.
21	*B*	..	"	"	228	..	14,065	..	..		21,000	..	..	The min. length of gap *a* = 1/16″
22	"	..	"	"	"	..	"	..	..	Air	23,500	..	..	" " " " " " " "
23	"	..	"	"	"	..	"	..	..		21,200	..	72,579-g	" " " " " " " "
24	"	..	"	"	"	..	"	..	..	Air	32,000	..	..	" " " " " " " "
25	*B*	..	0.1	13	228	..	14,065	..	..	Air	33,500	..	..	The min. length of gap *a* = 1/16″
26	"	..	"	"	"	..	"	..	..		23,500	..	..	" " " " " " " 3/16″
27	"	..	"	"	"	..	"	..	..	Air	27,000	..	72,579-ff	" " " " " " " "
28	"	..	"	"	"	..	..	..	..		17,800-19,000	..	..	Gap *b* broke when closing breaker.
29	"	..	"	"	"	..	..	..	..	Air	30,500-29,300	..	..	
30	*A*	0.1	0.00016	90	0	2370	13,940	12,060	..		24,600	31,000	..	
31	*C*	"	"	"	"	..	..	..	..		..	..	72,579-k	
32	"	"	"	"	"	..	..	..	..		..	..	72,579-l	
33	*A*	"	"	"	"	2370	13,940	12,060	..		24,600	30,000	..	
34	"	"	"	"	"	"	"	"			24,000	30,000	..	
35	"	"	"	"	"	2300	..	..	..	Air	24,000	31,400	..	
36	*C*	"	"	"	"	..	..	..	..	Air	..	..	72,579-m	
37	*A*	"	"	"	"	2300	..	..	..	Air	22,100	29,600	..	
38	"	"	"	"	"	"	..	..	..	Air	19,500	29,600	..	
39	"	0.1	"	"	228	"	12,420	..	..		19,000	29,200	..	
40	"	"	"	"	"	..	..	..	..		19,500	30,000	..	
41	"	"	"	"	"	..	..	..	..		20,800	31,500	..	
42	"	"	"	"	"	..	..	..	..	Air	20,700	27,700	..	
43	"	"	"	"	"	..	..	..	..	Air	20,800	26,200	..	
44	"	"	"	"	"	2180	..	..	..	Air	18,600	26,300	..	
45	*B*	..	"	"	"	2190	..	..	..	Air	11,200	..	..	Gap *b* broke down on closing breaker
46	"	..	"	"	"	"	..	..	..		16,800 once only	..	..	" " " " " " "
47	"	..	"	"	"	"	..	..	..		11,000	..	..	
48	"	..	"	"	"	"	..	..	..	Air	12,000	..	72,579-n	
49	"	..	"	"	"	"	..	..	..	Air	13,500	..	..	
50	"	..	"	"	"	"	..	..	..	Air	13,000	..	..	
51	*A*	0.1	0.00008	90	0	2190	13,140	..	..		25,200	31,500	..	
52	"	"	"	"	"	"	"	..	..		30,600	..	..	Gap *b* broke down on opening breaker
53	"	"	"	"	"	"	"	..	..	Air	24,500	30,500	..	
54	"	0.4	0.0008	"	"	2184	..	11,266	Too low for gap		24,800	38,300	..	Gap *b* broke on closing breaker
55	"	0.05	0.00032	"	"	2180	12,984	..	..		23,500-23,200	27,500-30,000	..	
56	*C*	"	"	"	"	"	"	..	..		..	..	72,579-o	
57	*A*	"	"	"	"	"	"	..	..		30,000	..	..	Occasionally, when breaker opened
58	"	"	"	"	"	"	"	..	..		20,000	25,200	..	
59	*C*	"	"	"	"	"	"	..	..		..	..	72,579-p	
60	*A*	"	"	"	"	"	"	..	..		26,000	30,500	..	
61	*C*	"	"	"	"	"	"	..	..	Air	26,000	30,500	72,579-q	
62	*A*	"	"	"	"	"	"	..	..	Air	24,000	..	..	
63	"	"	"	"	"	"	"	..	..	Air	..	26,700	..	
64	*B*	..	"	"	228	"	..	..	..		11,500	..	..	Gap *b* broke down when breaker closed
65	"	..	"	"	"	"	..	..	..	Air	11,300	..	72,579-r	
66	"	..	"	"	"	"	..	..	..	Air	11,700	..	..	
67	*C*	0.2	0.1	13	0	..	..	..	..		15,200	23,800		
68	"	"	"	"	"	..	..	..	..	Air	16,100	23,800	72,579-aa	
69	"	0.1	0	0	0	2250	13,380	..	..		24,000	..	..	
70	"	"	"	"	"	"	"	..	..		21,000	..	..	
71	"	"	"	"	"	"	"	..	..		29,000	..	..	
72	"	"	"	"	"	"	"	..	..	Air	26,800	..	72,579-gg	
73	"	"	"	"	"	"	"	..	..	Air	30,000	..	..	
74	"	"	"	"	"	"	"	..	..	Air	28,500	..	..	
75	"	"	"	"	"	"	"	..	..	Air	21,500	..	..	

TABLE II—*Continued*

Test	Circuit	C_1 μf	C_2 μf	R_d ohms	L_2 mh.	L_1 mh.	E_1 volts	E_2 volts	E_b volts	E_c volts	Kind of arc	b in volts	c in volts	Film No.	Remarks
76	*C*	0.1	0.1	99_c	13	0	2170	..	..	..	Air	11,000	18,000	72,579-y	When film was made L_1 = 228 mh.
77	"	"	"	53_c	"	"	"	..	..	..		10,500	18,700	72,579-t	" " " " " " "
78	"	"	"	53_c	"	228	2160	..	..	..	Weak air Insulator flashover	..	..	72,579-v, w, x	See note *a* for kind of arc
79	"	"	"	0	"	0	..	..	..	..	Weak air	..	19,000	..	
80	"	"	"	0	"	"	..	..	..	..	Strong air	..	19,500	..	
81	"	"	"	90_c	"	"	..	..	..	..	Air	..	19,500	..	
82	"	"	"	35_c	"	"	..	..	..	..	Air	..	19,500	..	
83	"	"	"	5_w	"	"	..	..	..	..	Air	..	20,100	..	
84	"	"	"	0	"	"	..	..	..	..	Air	..	20,100	..	
85	"	"	"	0.5_w	"	"	..	..	..	..	Air	..	20,500	..	
86	"	"	"	0.25_w	"	"	..	..	..	..	Air	..	20,500	..	
87	"	"	"	0	13	"	..	..	..	..	Air	..	20,500	..	
88	*C*	"	"	"	0	"	..	..	..	..	Air	..	19,000	72,579-u	When film was made L_2 = 228
89	"	"	"	0.5_w	"	"	..	..	..	..	Air	..	19,000	..	
90	"	"	"	0.25_w	"	"	..	..	..	..	Air	..	19,000	..	
91	"	0.2	"	"	"	"	..	..	..	..	Air	..	24,500	..	
92	"	"	"	0	"	"	..	..	..	..	Air	..	24,000	..	
93	"	"	"	5_w	"	"	..	..	..	..	Air	..	24,000	..	
94	"	"	"	50_w	"	"	..	..	..	..	Air	..	25,000	..	
95	"	"	"	200_w	"	"	..	..	..	..	Air	..	23,200	..	
96	"	"	"	"	13	"	..	..	..	..	Air	..	23,800	..	
97	"	"	"	50_w	"	"	..	..	..	..	Air	..	24,000	72,579-bb	When film was made R_d = 43 carbon
98	"	"	"	53_c	"	228	2160	..	..	..	Air	..	..	72,579-s	
99	"	"	"	5_w	"	0	..	..	..	..	Air	..	23,500	..	
100	"	"	"	115_w	"	"	..	..	..	..	Air	..	..	72,579-cc	
101	"	"	"	115_w	"	"	..	..	..	..	Air Flash over insulator	..	..	72,579-dd	See note *b*
102	*B*	..	0.1	"	13	228	..	..	..	..	Air	..	..	72,579-ee	

(*a*) R_c means resistance was carbon rod.
(*b*) R_w wire on tube 1 in. in diameter.

Discussion of Oscillograms

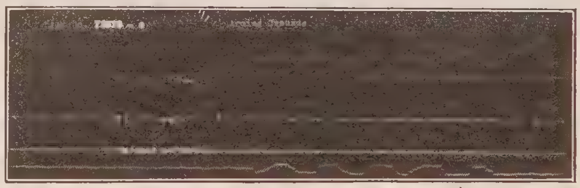
With the results of Table II indicating the probable correctness of Theory II, it is interesting to study the various oscillograms for evidences of the action called for by each of the three theories. In the oscillograms the zero lines are shown which represent zero current through the oscillograph element but do not represent the zero lines of the voltage waves. This is due to the fact that when zero voltage is impressed upon the grid there is still the plate current flowing through the oscillograph element.

Theory I

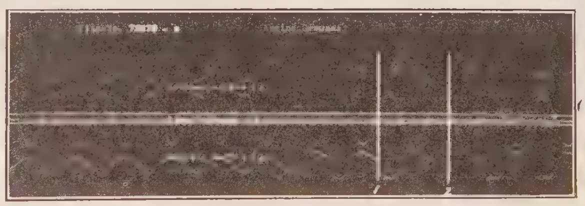
Theory I would require the appearance on the oscillogram oscillations of increasing amplitude during the periods that the arc was on. However, no oscillograms show this effect. Oscillograms 72,579-*d*, *o* and *z*, which are typical of those obtained with circuits *A* and *C*, show the oscillations through the inductance of the supply which were produced by the striking of the arc very clearly and these oscillations are clearly damped. An oscillation of the short-circuited condenser may be inferred by the slight breaks following each discharge in the curve for voltage across C_2. We may infer that these oscillations were highly damped because the curve becomes continuous again very shortly after. Oscillogram 72,579-*r*, taken with circuit *B* with a larger and lagging arc current, also shows only slight breaks in the curve for voltage across C_2.

Theory III

Theory III requires the extinction of the arc to take place at the peak of the high-frequency voltage wave so that when the arc extinguishes a charge is left on the condenser in excess of the charge corresponding to the



(72579-*O*)



(72579-*Z*)

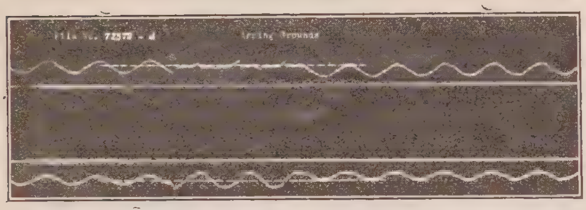
60-cycle voltage at that time. In no oscillogram was this observed. One would expect that the greatest chance for the Petersen theory to be valid would be when the short-circuited capacitance was small, for then the heating due to the dissipating of the energy of

the short-circuited condenser in the arc would be small, in fact, oscillogram 72-579-*o* does show the arc extinguish for a short time in nearly every half cycle. But even here the arc, after striking, held on long enough for the high frequency to damp out so that at the time of extinction the charge retained on the condenser did not exceed that corresponding to the instantaneous 60-cycle voltage. Thus, the displacement of the voltage waves was never in excess of the normal voltage to neutral as is required by this theory.

Theory II

Theory II requires the striking of the arc at the peak of the 60-cycle voltage wave and its extinction also near the peak of a 60-cycle voltage wave. When the striking of the arc took place after the arc had been out for a little time, that is, more than a half cycle, the striking always did take place at the peak of the voltage but when an air blast was used so that the arc would be blown out before the gap had become very long, reignition frequently occurred within the next half cycle before the peak of the voltage wave as shown at 1, oscillogram 72,579-*z*. Also when an air blast was used extinction sometimes occurred before the peak of the voltage, that is, before the 60-cycle charging current would normally pass through zero. However, these extinctions and reignitions give rise to voltages less than those called for by Theory II since the retained charge under these circumstances would be less than that corresponding to peak voltage and the amplitude of oscillation would be less because of the smaller total voltage to ground at the moment of striking. We may say then that the voltages called for by Theory II do not develop with each individual extinction and reignition of the arc, but we can say that usually when the arc extinguishes for a longer time it will do so at the peak of voltage with a retained charge equal to normal voltage to neutral and that the next striking of the arc will be at the peak voltage so that the maximum voltages

(72579-*R*)



(72579-*D*)

called for by this theory will nearly always be ultimately developed. The final extinction of the arc at the peak of the voltage wave and the displacement of the voltage waves from the zero line are clearly seen in oscillograms 72,579-*d* and *o*.

The spark gap voltages obtained and the oscillograms appear to substantiate Theory II as to the maximum voltages which may be developed by an arcing ground. However, it must be pointed out that the experimental work was limited to a 13,200-volt circuit and it is conceivable that for higher voltages with greater arc lengths in which heating of the electrodes might play a smaller part, Theory III calling for the extinction of the arc at zero of high-frequency current might find application. The authors' opinion is that this will seldom prove to be the case. As to Theory I calling for the development of high voltages due to the "negative resistance" of the arc they are even more strongly of the opinion that it will fail to be realized even with higher voltages.

Grounded vs. Ungrounded Neutral Systems

In the experiments described above circuits A and C approximate conditions on a transmission system with an isolated neutral and circuit B approximates conditions on a grounded neutral system. The predictions of Theory II applied to circuit C were substantiated both by spark gap voltage determinations and by oscillograms. This theory applied to a three-phase system calls for displacement of neutral relative to ground and the development as a result of transient oscillations of maximum voltage of $3\frac{1}{2}$ times normal voltage to neutral on the sound phases and two times normal voltage to neutral on the grounded phase. In a grounded neutral system if the impedance between neutral and ground is not too large the charge left on the system after the extinction of the arc will be drained off before the next striking of the arc. Hence the maximum voltage which will be developed will be that corresponding to 2, Fig. 5, that is, $2\frac{1}{2}$ times normal voltage to neutral on the sound phases and 1 times normal voltage to neutral on the grounded phase.

Thus the maximum voltages to ground developed by arcing grounds on isolated neutral and grounded neutral systems, respectively, are in the ratio $3\frac{1}{2}$ to $2\frac{1}{2}$. However when the distribution of potentials within apparatus is considered, the magnitude of sudden changes in voltage becomes important and these sudden voltage changes are very much greater in the isolated neutral case than in the case of the grounded system. We must, therefore, consider the surges set up by arcing grounds which are propagated due to the distributed capacitance and inductance in transmission systems.

Traveling Waves Set up by Grounding Phase of Transmission System

The transient oscillations generated by grounding a phase in a transmission system were described above in terms of lumped capacitances and inductances. When

the capacitances and inductances are distributed, oscillations take place but are not simple sine waves as were described above. These oscillations are best pictured in terms of traveling waves. Referring to Fig. 14, when a ground suddenly occurs on a phase of the transmission line the capacity of the line is not discharged as a whole like a single condenser but those parts of the line nearest to the grounded point discharge first. Since the inductance to the grounded point is less for these nearest parts, they discharge almost at once while the farthest parts of the line still retain their charge. There are thus set up waves traveling in both directions from the point of ground. These traveling waves reduce the potential from V, the value just before the ground occurred to zero. When the traveling wave reaches the end of the line where a change of impedance is encountered, reflection occurs and at the point of reflection a sudden change of voltage takes place amounting to $\frac{2\,Z_2}{Z_1 + Z_2}\,V$, where Z_1 and Z_2 are respectively the surge impedance of the line and the surge impedance of the apparatus at the end of the line. The mathematical derivation of this expression may be found in the appendix.

The oscillations of the ungrounded phases are also accompanied by traveling waves but owing to the inductance of the supply system which is in series, the wave fronts will be of much less steepness and therefore much less disastrous as regards voltage distribution within the apparatus at the ends of the line.

We may now compare the magnitudes of the traveling

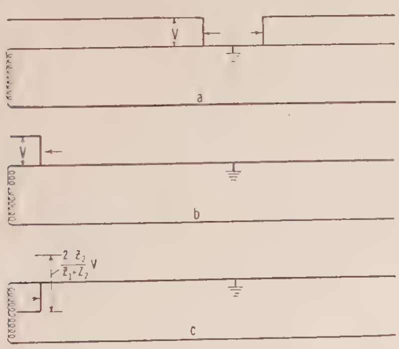


Fig. 14—Propagation and Reflection of Traveling Wave

waves set up by an arcing ground in the two cases of the isolated neutral and the grounded neutral systems. For the isolated neutral system we have seen that the arc will usually strike at the maximum of the 60-cycle voltage wave and at that moment there will also be a retained charge on the system after the previous extinction which further displaces the voltage of the line from ground. The voltage of the line to ground is then two times the normal voltage to neutral. The magnitude of the sudden change in voltage which occurs at the end of the line is therefore

$$\frac{2\,Z_2}{Z_1 + Z_2} \times 2\,E,$$

or nearly four times normal voltage to neutral. For the grounded neutral system there is no charge retained by the system at the moment the arc strikes and therefore we have $V = E$. Hence the sudden change in voltage due to reflection at the end of the line will be

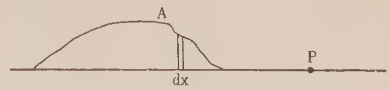


Fig. 15—Traveling Wave on Transmission Line

approximately $2\,E$ or only one-half as great as that for the isolated neutral system. Most observations of abnormal voltages on isolated neutral systems due to arcing grounds have been not of voltages to ground but of voltages across parts of apparatus. The above discussion of the traveling waves set up by arcing grounds on isolated neutral systems show that this is what should be expected.

Appendix

Reflection of Traveling Waves

Consider a traveling wave started by any abrupt change in potential on a system containing distributed inductance and capacitance. The wave may start with an abrupt or sheer front such as results when closing a switch on a dead line or grounding an energized line or it may start with a tapered front such as may be induced by the release of an electrostatic charge on a cloud. As the traveling wave proceeds on its course it gives up energy in Joulian heat and radiation which causes a progressive tapering of its front. When this traveling wave strikes a point on the line where the impedance of the line makes an abrupt change the wave undergoes a reflection. The theory of such reflection follows. In Fig. 15 let A represent a traveling wave of voltage of any shape and let v be its potential at any point x.

Let L = inductance per unit length of line.

Let C = capacitance per unit length of line.

Then
$$\Delta v = -L\,\Delta x\,\frac{d\,i}{d\,t} \tag{1}$$

$$\Delta i = -C\,\Delta x\,\frac{d\,v}{d\,t} \tag{2}$$

from (1)
$$\frac{\partial v}{\partial x} = -L\,\frac{\partial i}{\partial t} \tag{3}$$

from (2)
$$\frac{\partial i}{\partial x} = -C\,\frac{\partial v}{\partial t} \tag{4}$$

from (3) $$\frac{\partial^2 v}{\partial x^2} = -L \frac{\partial^2 i}{\partial t \partial x} \quad (5)$$

from (4) $$\frac{\partial^2 i}{\partial t \partial x} = -C \frac{\partial^2 v}{\partial t^2} \quad (6)$$

from (5) and (6) $$\frac{\partial^2 v}{\partial t^2} = \frac{1}{LC} \frac{\partial^2 v}{\partial x^2} \quad (7)$$

also $$\frac{\partial^2 i}{\partial t^2} = \frac{1}{LC} \frac{\partial^2 i}{\partial x^2} \quad (8)$$

It is readily checked by substitution that

$v = f(x + \alpha t)$ and

$v = g(x - \alpha t)$ are solutions of (8)

f and g denoting arbitrary functions of $(x + \alpha t)$ and $(x - \alpha t)$, respectively, and

$$\alpha^2 = \frac{1}{LC}$$

For, substituting $v = f(x + \alpha t)$ in (7) we get

$$\alpha^2 f''(x + \alpha t) = \frac{1}{LC} f''(x + \alpha t)$$

or $$\alpha^2 = \frac{1}{LC}$$

$v = f(x + \alpha t)$ evidently represents a voltage wave traveling with the velocity α in the direction of negative x; for if we increase t by unity and at the same time decrease x by α the value of v is unchanged; but increasing t by unity and changing x by $-\alpha$ is equivalent to shifting the wave through the distance $-\alpha$ in unit time. Similarly, $v = g(x - \alpha t)$ represents a voltage wave traveling in the direction of positive x.

Let us now determine the traveling wave of current which accompanies the voltage wave $v = f(x + \alpha t)$, substituting, $v = f(x + \alpha t)$ in (3) and (4), we get

$$-L \frac{\partial i}{\partial t} = f'(x + \alpha t) \quad (9)$$

$$\frac{\partial i}{\partial x} = -C \alpha f'(x + \alpha t) \quad (10)$$

Integrating (9) $i = -\dfrac{1}{\alpha L} f(x + \alpha t) + F_1(x)$ (11)

Integrating (10) $i = -C \alpha f(x + \alpha t) + F_2(t)$ (12)

since $\dfrac{1}{\alpha L} = C \alpha, F_1(x) = F_2(t)$

$F_1(x)$ and $F_2(t)$ therefore represent a constant current and can be neglected in considering the traveling wave. We have then, finally

$$i = -\frac{f(x + \alpha t)}{\alpha L} = -\frac{f(x + \alpha t)}{\sqrt{L/C}} = -v/Z \quad (13)$$

where $Z = \sqrt{L/C}$ = surge impedance.

In the same way we may determine the current wave corresponding to $v = g(x - \alpha t)$ and find

$$i = \frac{f(x - \alpha t)}{\alpha L} = v/Z$$

Consider now a traveling wave $v = f(x + \alpha t)$ reaching a point P at $x = 0$ where the line constants change from a surge impedance of Z_1 to surge impedance Z_2. There will then appear a transmitted and reflected wave in addition to the oncoming wave. Before reaching P we have only the advancing wave

$$v = f(x + \alpha t) \quad (14)$$

$$i = -1/Z_1 f(x + \alpha t) \quad (15)$$

After reaching P we have on one side a transmitted wave.

$$v_2 = f_2(x + \alpha_2 t) \; x < 0 \quad (16)$$

$$i_2 = -1/Z_2 f_2(x + \alpha_2 t) \; x < 0 \quad (17)$$

And on the other side of P the oncoming plus reflected wave

$$v_1 = f(x + \alpha t) + g(x - \alpha t) \; x > 0 \quad (18)$$

$$i_1 = -1/Z_1 f(x + \alpha t) + 1/Z_1 g(x - \alpha t) \; x > 0 \quad (19)$$

At point P where $x = 0$ the voltage from either side must be the same and the current flowing to P on one side must equal the current flowing from P on the other side. Therefore from (16), (17), (18) and (19)

$$f_2(\alpha_2 t) = f(\alpha t) + g(-\alpha t) \quad (20)$$

$$-1/Z_2 f_2(\alpha_2 t) = -1/Z_1 f(\alpha t) + 1/Z_1 g(-\alpha t) \quad (21)$$

multiplying (21) by Z_1

$$-Z_1/Z_2 f_2(\alpha_2 t) = -f(\alpha t) + g(-\alpha t) \quad (22)$$

subtracting (22) from (20)

$$(1 + Z_1/Z_2) f_2(\alpha_2 t) = 2 f(\alpha t)$$

$$f_2(\alpha_2 t) = \frac{2}{1 + Z_1/Z_2} f(\alpha t)$$

or $$v_2 = \frac{2v}{1 + Z_1/Z_2} = \frac{2 Z_2}{Z_1 + Z_2} v. \quad (23)$$

Therefore the transmitted voltage and also the oncoming plus reflected voltage has a ratio to the oncoming voltage of $\dfrac{2 Z_2}{Z_1 + Z_2}$ irrespective of the nature or shape of the wave.

The Distance Relay for Automatically Sectionalizing Electrical Net Works

BY LESLIE N. CRICHTON

Member, A. I. E. E.

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Review of the Subject.—*This paper describes a new relay for automatically sectionalizing transmission lines, similar to existing relays in many respects, but equipped with "brains" so that it can determine the location of the trouble and govern its operation accordingly. For dead short circuit its time of operation is proportional to the distance from the short circuit so that when it is used the circuit breaker nearest to the trouble always trips out first. When applied to any system it is adjusted to fit the particular length of line which it controls and no change in this setting need ever be made due to operating conditions on the remainder of the system.*

Its discrimination is obtained by a time limit which varies directly as the voltage and inversely as the current existing during the trouble. It has the incidental advantage that since the circuit breaker nearest to the trouble is opened first, the final breaker to open is the one having the longer section of line in series with it to limit the current and therefore decrease the duty required of the circuit breaker.

CONTENTS

A Relay Which Determines Its Own Time of Operation

THIS is a new device, which when trouble occurs, makes a calculation to determine its location. If the trouble is close to the switching point at which the relay is situated, the relay will operate quickly to disconnect the disabled section. If, however, the trouble is a long way off, the relay will operate slowly in order to allow any other relay which might be nearer to the trouble to act first.

Because this device adjusts its time of operation to suit the location of the trouble, it will operate on the most complicated sort of network; in fact, the more complicated the network, the more favorable are the conditions for its correct operation. In the past, reasonably satisfactory sectionalizing has been obtained by means of over-current and directional relays equipped with time limit features. The general scheme of operation has been to adjust the relays farthest from the power house with a short time limit and to increase this time limit on those relays which are located nearer to the power station. On a complicated system this is rather difficult and in some cases impossible, for instance, in the case of tie lines between two generating stations.

The Basis of Calculation

In determining the distance, the relay makes use of Ohm's law and bases its calculation upon the value of the current and voltage existing at the time of the short circuit. A simple form of distance relay is shown in Fig. 1 wherein a current coil is shown arranged to close the relay contacts while a voltage coil is so arranged that, as long as voltage is applied, it will tend to overpower the current coil and prevent the contacts from being closed. These two coils are proportionate so that on the particular section of line to which they are applied the current coil will just overpower the voltage coil when a short circuit occurs at the far end of the section. If a short circuit should occur in the next section, the voltage across the potential coil of the relay will be higher and will thus prevent it from operating, whereas, if the trouble is within that section of line and close to the relay, the voltage will be lower and the relay's action, therefore, more positive. With trouble immediately at the relay, the voltage will of course be zero and, therefore, the voltage coil will offer no opposition to the operation of the current coil. Another way of looking at this simple relay is to assume that the two coils are balanced against each other and that the circuit is divided into two branches, one branch going through the voltage coil having a fixed resistance and, therefore, taking a current which is proportional to the voltage, and the other branch consisting of the current coil in series with the section of line. This latter branch is of variable resistance depending upon the location of the short circuit and the coils are so designed that the current coil will just overbalance the voltage coil when

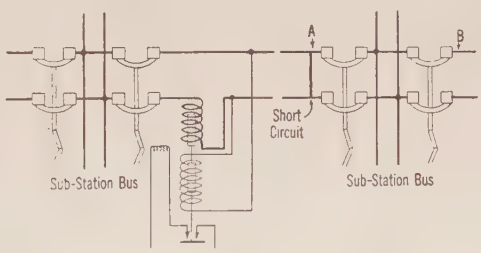

FIG. 1—PART OF A NETWORK SHOWING A SINGLE SECTION OF LINE AND AN ELEMENTARY DISTANCE RELAY

One defect is that it cannot distinguish between a short circuit at *A* and one at *B*.

Presented at the Spring Convention of the A. I. E. E. Pittsburgh, Pa., April 24-26, 1923.

the resistance is its maximum. Therefore, when the short circuit is beyond that section of line, *i. e.*, when the resistance of that particular branch becomes greater than that required to balance the relay, the relay will not operate. On the other hand, when the resistance is less than that of the full section of line, *i. e.*, when the short circuit is closer to the relay, the unbalance will be still more pronounced and the relay action more positive.

The simple relay mentioned in the preceding paragraph has two obvious defects. First, it will not work properly if the short circuit should in itself have some resistance, which resistance, being an unknown factor, would be difficult to take into account. Second, it is unable to properly discriminate in case of trouble occurring close to the substation at the other end of the section, *i. e.*, the relay cannot tell whether the trouble occurs at A or B. This simple relay would furthermore be unable to clear trouble in a distant section which for some reason had not been cleared by the proper circuit breakers on that section.

The remedy for all these defects is simple; design the relay so that when the trouble is close, it will operate instantaneously, but when the trouble is some distance away it will operate slowly so as to allow any relay which is nearer to the trouble to act.

Mechanical Principle

The principle of the time-limit distance relay is shown schematically in Fig. 2. This relay is of the induction type, the disk being rotated by the current coil whenever the current reaches sufficient magnitude, —the movement of the disk being damped by the

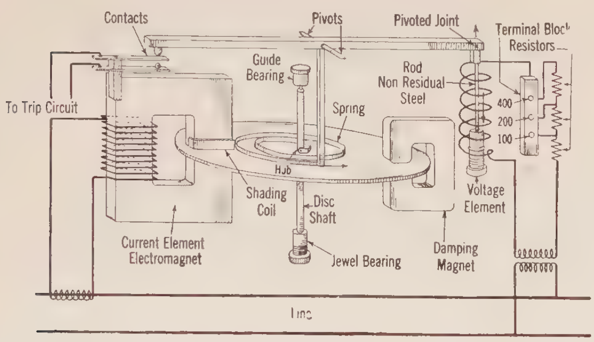

Fig. 2—Schematic Diagram of C Z Distance Relay

permanent magnet so that its speed is roughly proportional to the current. The movement of this disk does not directly close the contacts but instead it tightens a spiral spring. On the other end of this spring is fastened a lever which is pivoted at the center and which has the contacts on one end and the core of the voltage coil on the other. This voltage coil is so arranged that it opposes the closing of the contacts. When in the neutral position all parts of the relay are nicely balanced so that if there is no voltage on the voltage coil a very slight movement of the disk will close the contacts. Similarly, if voltage is applied to the restraining coil, its pull will prevent the contacts from being closed until the spring has been tightened up sufficiently to overcome it and since the motion of the disk is damped, this will require some time.

Mathematical Principle

It is evident that for a given voltage on the voltage coil the spring must be tightened to a certain definite point before the pull of the voltage coil can be overcome and, therefore, if the voltage is maintained constant the

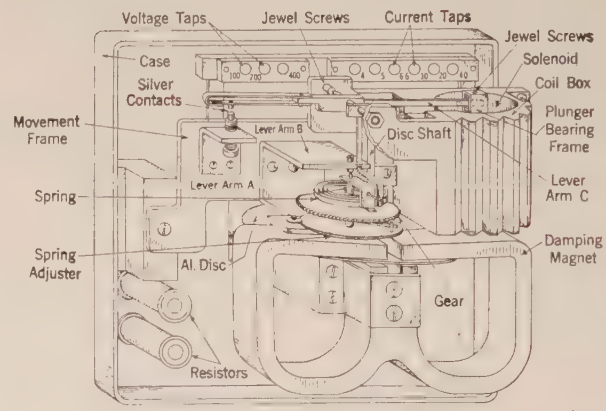

Fig. 3—Distance Relay Type C Z

time required for the relay to close its contacts will vary inversely as the current, or stated mathematically:

$$T \text{ varies as } 1/I$$

Similarly if the current is maintained constant with a resulting constant speed of the disk, the time required for the contacts to close will vary directly as the voltage, or stated mathematically:

$$T \text{ varies as } E$$

Combining these two we have

$$T = E/I = Z = \text{distance}$$

Important Details of Design

The principle which has just been described is exceedingly simple but the actual design of the relay was quite difficult, principally because of the requirements that, during time of trouble, it must discriminate between different voltages of very small value, whereas, during normal operation, the voltage coil must be able to withstand full voltage continuously. Part of the method of overcoming this trouble has been to cast cooling ribs on the case containing the potential coil, as shown in the accompanying photograph and the schematic view, Fig. 3. This loss is only about 8 watts but it is generated in a coil no larger than an ordinary spool of thread. As a result of this design, the voltage coil will discriminate quite positively between zero voltage and 5 per cent of normal voltage. At first, difficulty was encountered due to the effect of residual magnetism when suddenly reducing the voltage from normal to a small value, but this has been overcome by using a core of a

special non-residual steel developed by Dr. T. D. Yensen of the Westinghouse Research Laboratory.

The inherent characteristics of the induction disk are such that within a moderate range its speed varies directly as the current so that no particular difficulty was encountered in designing the current element. But the voltage coil presented difficulties which required

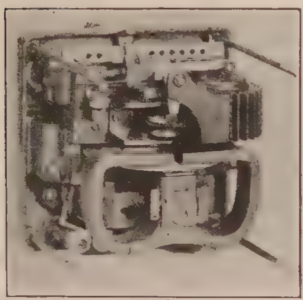

Fig. 4a

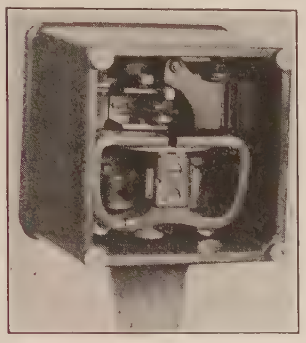

Fig. 4b

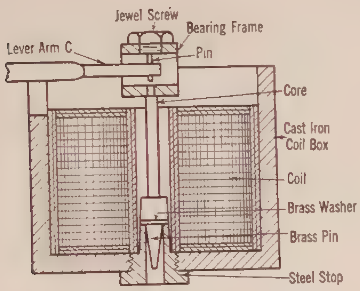

Fig. 5—Type *C Z* Distance Relay Details of Potential Coil

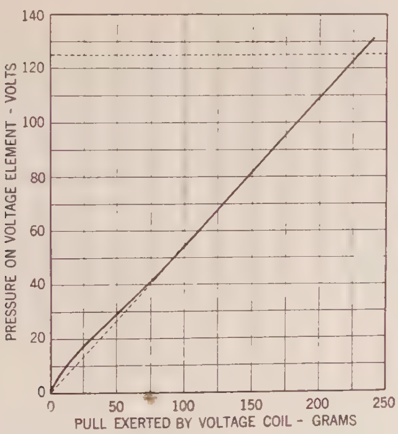

Fig. 6—Type *C Z* Distance Relay Voltage-Pull Curve

painstaking work to overcome. Finally the design shown in Fig. 5 was worked out to provide a device having a straight line characteristic, of rugged construction, free from the effects of friction, quick in its response, and accurate. The straight line characteristic, which was quite satisfactorily attained as shown in Fig. 6, is due to the use of a core of small cross section which saturates at a low voltage so that above this value the pull varies directly as the voltage. It should be observed that at normal voltage the pull on the core is almost 0.5 lb. Of course it is proportionally less at lower voltages but it is far from being the delicate device that might be imagined. This heavy force is required in order to insure adequate pressure on the contacts as well as to minimize the effects of friction. Friction is still further reduced and the effects of wear practically eliminated by careful jewelling of the important bearings.

Characteristics

It has been customary with the older types of relays

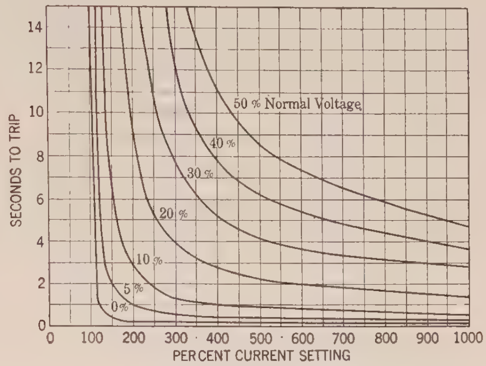

Fig. 7—Type *C Z* Distance Relay Time-Current Curves at Various Voltages

to plot current—time curves and for this reason it will be interesting to observe in Fig. 7 a family of current-time curves taken at various voltages. These curves are complete but in order to make the best use of the data contained therein it is preferable to plot distance-time curves as shown in Fig. 8. This group of curves refers to one particular system having a specified voltage, size of conductor and spacing between conductors. The curve *B* was first plotted by assuming a definite primary current and length of line and from these

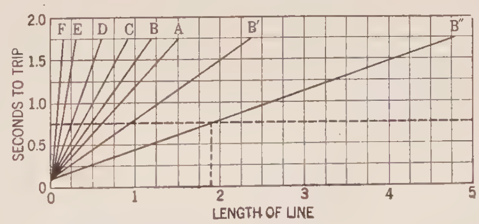

Fig. 8—Time-Distance Curves Type *C Z* Distance Relay

figures calculating the percentage drop in voltage. The time corresponding to this voltage was then taken from Fig. 7 and the position of the straight line *B* therefore determined.

The curves in Fig. 8 are not run up very high in time because we are not much interested in the long time characteristics of the relay. Its object is to clear trouble as quickly as possible and all adjustments should be made with that end in view. If, for instance, in Fig.

9, trouble should occur at X the relay at A should operate in, say, 0.1 second. The circuit breaker will require about 0.25 second to open, the total time required to clear the short circuit being 0.35 second. Now the relay at B should have sufficient time delay so that it will not close its contacts before the breaker at A has had a chance to open (0.35 sec.). If we double this time in order to allow an ample margin of safety, we will then have a reasonable setting for the relay at B. Therefore, we have drawn the dash line across Fig. 8 to indicate the maximum time which should be required to operate any relay. This is the extreme case; the average short circuit will be cleared in considerably less time. This difference in time between adjacent stations is of course due to the difference in voltage between them. With the present design of relay the difference in voltage between two consecutive stations carrying the same trouble current must be at least 5 per cent in order to secure proper discrimination.

All of the preceding argument is based upon the assumption that trouble always consists of "dead" short circuits which the writer believes to be the case. If we

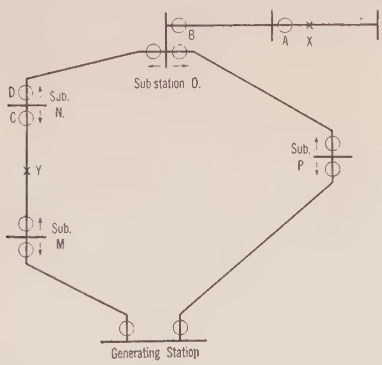

Fig. 9

assume that a high-resistance short circuit exists, it will increase the time of operation of the relay but this is not particularly serious because this resistance will also cut down the value of the current so that the shock to the system is not so great and can be withstood for a longer time.

Adjustments

Consider curve B in Fig. 8 which has been plotted from the relay characteristics given in Fig. 7, and assume that the ampere turns on the current coil are reduced to one half. Therefore, with our assumed current, the disk will rotate at half speed which will allow the voltage to be reduced to half its value in order that the relay may operate in the same length of time. In other words by reducing the ampere turns on the current coil to one half we can reduce the distance by an equal amount, thus giving a curve D. Similarly by again halving the number of turns, curve E can be obtained. Similarly the other curves in the group are obtained by means of taps on the current coil.

Suppose the section of line to which we wish to apply this relay is so long that the adjustment shown on curve B is unsatisfactory. We leave the current adjustment as it is and place sufficient resistance in series with the potential coil so that its current is cut to half its original value. Therefore, in order that the pull on the coil shall be the same with a consequent equal time of operation, it will be necessary to double the voltage, which can only be done by doubling the length of the section of line. Thus, we get curve B' and similarily by again doubling the resistance of the potential circuit we double the distance and obtain B''. The other curves can be similarly extended so that adjustments can be made which are suitable to intermediate length of line section. It is thus seen that by two very simple adjustments the relay can be set to work properly on sections of lines whose length vary as much as 40 to 1.

Method of Setting Relay

The unit of distance shown in Fig. 8 depends upon the size of the conductor, the spacing between them and the voltage of the system, all of which must be taken into account when setting the relay. It is also necessary to consider the ratio of the potential and current transformers, so that the total possible number of combinations is enormous, and in order to make the task of adjusting relays an easy one, it is important that the manufacturer of the device furnish curves or tables for systems of various voltages and various sizes of conductor showing the distances corresponding to the different relay settings. When the data are arranged in this way the problem of setting the relays is an easy one, it being necessary only to determine the distance between the switching stations to which the relay is to be applied and picking off the proper relay setting from the table. As a rule no calculations are necessary, although it may be occasionally advisable to make a rough check of the short-circuit current available in order to make sure that there will be sufficient current to operate the relay. Long and laborious calculations of the short-circuit currents available at all points of the system are certainly unnecessary. Likewise, it will not be necessary to determine the short-circuit current by means of calculating tables and similar devices.

Its Use on Grounded Neutral Systems

When a short circuit occurs between two wires on a 3-phase system, the potential coil of the relay must, of course, be supplied with delta potential so that it can make its proper determination of the distance. On the other hand, it should be supplied with star voltage when a short circuit occurs between one wire and ground on a system having a dead grounded neutral. It, therefore, appears that two sets of relays should be used on such a system, one to clear short circuits between wires and

the other to clear grounds. On a system having its neutral grounded through a resistance, other relay schemes must be used to clear grounded conductors.

The Directional Element

In addition to the distance determining element which has been described this relay will usually require a directional element in order to definitely locate the direction of the trouble as well as its distance away. For example in Fig. 9, which represents a rather simple distribution system, it is quite evident that if trouble should occur at *Y*, both relay *C* and relay *D* at substation *N* would have the same current and voltage actuating them so that they would both try to open their circuit breakers. In order to prevent such improper operation, each relay should be equipped with a directional element which has its contacts in series with the distance contacts and acts as a sort of "check valve" to prevent the relay from operating when power is flowing toward the bus bars. Therefore, in the figure relays *B* and *D* are each shown equipped with directional

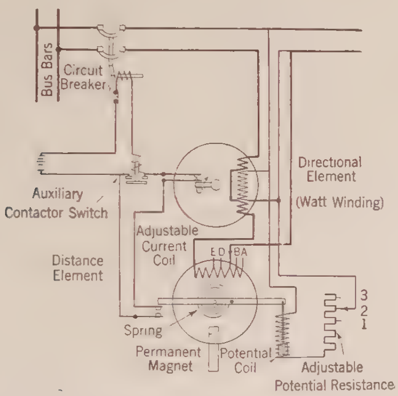

Fig. 10—*C Z* Relay Elementary Diagram

element so connected that they will allow their respective relays to operate only when power is flowing away from the bus bars. Similarly the relays at substation *M* and in fact the relays on all the substations around the loop should be equipped with directional elements as shown. Of course directional elements are not necessary at the generating station and at other points where power can flow only in one direction.

This directional element is similar to the one which has been used so successfully for the past 8 or 10 years and consists of a very sensitive watt-indicating device without mechanical restraint of any nature and so sensitive that it will operate under the most extreme possible conditions of low voltages on the system. This directional element will easily discriminate on 1 per cent of normal voltage if the short-circuit current through the relay is, say, 5 or 6 times normal. This condition is easily obtained during short circuit; in fact it is unusual to have the voltage drop to as low a value as 1 per cent of normal.

In Fig. 10 is shown a complete diagram of internal connection of the distance relay including the directional element and the adjusting taps. It should be noted that during normal conditions on the system a large number of the directional elements will have their contacts closed, but this is a matter of no importance because the cooperation of the distance element is necessary before a circuit breaker can be tripped. Therefore, the question of normal direction of power flow has nothing whatever to do with the setting or adjustment of the relay.

Method of Connecting Relay in the Circuit

The experimental work which has finally resulted in the production of this relay was begun quite a number of years ago and one of the earliest fruits of the work was the startling discovery that the directional element cannot be connected in the circuit as though it were an ordinary wattmeter intended to measure power consumption. Although the problem was quite baffling at first, it was found that there were several easy solutions, the best one being to connect the current coil of the directional element so that it utilizes the star current (the current in the line wire) and connect the potential coil so that it uses the delta voltage of the system having a phase relation 30 deg. behind the current. This scheme has been successfully used for a number of years on the present type of directional overcurrent time-limit relay and it is usually assumed that this lag in the voltage circuit is for the purpose of enabling the watt element to work under a little better power factor condition when the current lags due to the low power factor of a highly inductive short circuit. While this is, of course, an advantage, the principal reason for using the connection is that it prevents improper operation of the relays under badly unbalanced conditions such as will always occur when only two wires of a 3-phase circuit are short-circuited. For example if the two coils of the relay should make use of the star current and star voltage of the circuit, it would be theoretically possible to have short circuits of such a nature that the current in the relay would, in effect, lag 180 deg. behind the voltage so that the relay would operate in the opposite direction from what it should do.

In order to more thoroughly investigate this subject and check some of the theories, an elaborate 3-phase artificial transmission line was constructed. This part of the work is described in a paper on the artificial transmission line presented before the A. I. E. E., by Mr. George H. Gray, in 1917. The conditions which exist at numerous points of a large transmission system, during almost every conceivable kind of ground and short circuit were studied and classified in a number of diagrams and charts which makes the subject easily understood. It is, therefore, unnecessary to discuss the subject in this paper.

Advantage of the Distance Relay

All dead short circuits will be cleared within one second and the majority of them in considerably less time.

Trouble will be cleared with equal rapidity from all parts of the system.

The breaker furthest from the trouble opens last, thus insuring the insertion of considerable impedance in the path of the short circuit before finally interrupting it. This reduces the strain on the breaker, and, in effect, converts every breaker on the system into a "resistance type" breaker.

It does not require an excessive amount of mathematical calculations when applying it to the distribution systems.

Conclusion

Although the distance relay as described in this paper is a new idea, it can hardly be said to be entirely untried because its use does not involve a large number of new mechanical devices or new electrical connections. The induction type of protective relay has been thoroughly tried out and found to give excellent service. The directional element has given the same good service and likewise the method of connecting it into the circuit has been thoroughly approved by years of experience. In effect, the well known directional time-element overcurrent relay has been taken and been given sufficient "brains" to enable it to determine what time limits it should have in its particular location.

ELECTRIC PUBLIC-UTILITY POWER PLANTS INCREASE PRODUCTION

A remarkable increase throughout the United States in efficiency in the use of fuel and the production of electricity during the past four years is seen in a statement just issued by the Department of the Interior, through the Geological Survey.

The statement indicates that electric public-utility power plants produced more electricity in 1922 than ever before, and that over one-third of the total amount produced was generated at water-power plants, thereby conserving over 20,000,000 tons of coal in 1922. New York is the leading state in the production of electricity by public-utility power plants and California is the leading State in the production of electricity by the use of water power. One-fifth of the total amount of electricity produced by water power in the United States is produced by California hydroelectric power plants.

Reports on the monthly production of electricity and consumption of fuel by electric public-utility power plants in the United States are now being published by the Geological Survey. These reports were started in 1919, covering the months of February, March, April, July, September and October in that year, and have been published each month beginning with January 1920. They show the output of central stations, municipal plants, plants generating electricity for the operation of street railways and electrified steam railroads, and the portion of the output of a few manufacturing plants that is sold for public use.

A summary of the monthly reports has been prepared and is now available for general distribution. The following information arranged in 16 tables is included in this summary:

Tables 1 to 3 show for each State for the years 1920, 1921 and 1922 the total annual production of electricity, the amount produced by water power and by fuel power, the proportion of the total for the United States formed by each State's total annual output, output by water power, and output by fuel power, and the ratio of each State's output by water power and by fuel power to the State's total output. Tables 4, 5 and 6 show each State's annual consumption of coal, oil and gas in the production of electricity and its proportion of the total consumption in the United States. Table 7 shows the amount of electricity generated by the use of wood for fuel. Tables 8 and 9 give the total annual production of electricity in the United States by public-utility power plants, the amount produced by water power and by fuel power, the proportion of each to the year's total, the annual fuel consumption, and the change in output and fuel consumption from one year to another for each year from 1919 to 1922.

The remarkable increase in the efficiency in the utilization of fuel in the 4 year period is shown in Table 10. In 1919 the average consumption of coal required to generate 1 kilowatt-hour of electricity was 3.2 pounds; in 1922 but 2.5 pounds was required, a decrease of 22 per cent representing a saving of millions of tons of coal.

Tables 11 to 16 show the relative rank of the 10 leading States in 1920, 1921 and 1922 in total annual output by water power and by fuel power, and consumption of coal, oil and gas utilized in the production of electricity. New York is the leading State in the total production of electricity, Pennsylvania is second, and California is a close third. In 1920 New York was the leading State in the production of electricity by the use of water power. In 1921 California took first position, and the figures for 1922 indicate that it will probably maintain this position for some time to come. The tables showing the relative rank by States in the consumption of the several fuels show that California in 1920 utilized in generating electricity 43 per cent of the total quantity of oil so consumed in the United States, but in 1922 California used only about 20 per cent of the total, Texas taking first place, with a consumption of 23 per cent. California's decrease in the consumption of oil for generating electricity is of course due to the progress in water-power development in that State.

Copies of the summary may be obtained on application to the Director of the Geological Survey at Washington.

Some Engineering Features of the Weymouth Station of The Edison Electric Illuminating Co. of Boston

BY I. E. MOULTROP
Member, A. I. E. E.
Edison Electric Ill. Co., Boston

and

JOSEPH POPE
Stone & Webster, Inc.

Review of the Subject.—*The new power station of The Edison Electric Illuminating Company of Boston, now under construction on the Weymouth Fore River is expected to have an ultimate capacity of about 300,000 kw. The present construction covers the installation of two 32,000 kw. generating units with three 1974-h. p. boilers, operating at 375 lb. steam pressure and 700 deg. fahr. In addition, a single boiler to carry steam at pressures up to 1200 lb. is to be installed. This boiler will have about the same heating surface as the normal pressure boilers. The steam generated by it will pass through a pressure reducing turbine developing about 2000 kw., and will be exhausted at 375 lb. pressure. After being reheated to the original temperature of 700 deg. the steam will be piped to the main header and used in the large turbines. If satisfactory results are obtained from the higher-pressure boiler-turbine units more of them will be installed. Three will be required to furnish sufficient steam to operate one of the 32,000-kw. units.*

The maximum steam temperature was fixed at 700 deg. in consideration of the properties of materials at the higher temperatures. While the theoretical gain from higher pressure increases up to the maximum for which any data are available, the full benefit of the thermodynamic possibilities are not at present obtainable in practise without reheating the steam at some point intermediate between the throttle and the condenser. Without reheating, the most advantageous steam pressure, both practically and economically considered, seems to be about 375 lb. gage. With reheating, it appears that about 1200 lb. is a practicable initial pressure, and that 375 lb. is an entirely satisfactory pressure at which to reheat. Accordingly a combination of these two pressures with intermediate reheating has been adopted; the higher pressure with a view to developing its possibilities, the lower pressure with the feeling that it represents the best practise in the single expansion cycle and that operation solely at that pressure will give highly economical results. The character of the future development of the plant will depend upon the relative performance of the two classes of equipment.

Feed water is to be heated by two-stage bleeding of the main units and by economizers. All normally running auxiliary equipment is to be driven by alternating-current motors. Power for driving the essential auxiliaries is to be supplied from a 2300-volt alternator of 2500 kv-a. capacity connected directly to each 30,000-kw. main generator shaft, and thus driven by the main turbine, which will have sufficient capacity for driving both generators at full load. This arrangement is expected to give a combination of greater economy and security than any heretofore used.

The switch house will be a separate structure, four stories and basement. The upper floor will carry the switchboard and the switch operating mechanism. The three lower stories will house the bus structures, oil circuit breakers and reactors, each phase being isolated to a single floor. The basement will serve as a cable vault and all incoming and outgoing circuits will pass through it. There will be two main ring busses and a transfer bus. The ring busses will be divided into sections, each section fed by two generators and with current-limiting reactors between sections. All circuits will be connected to the busses through two oil circuit breakers in series.

No prediction is made of the expected operating performance of the station, but it is calculated that under ideal conditions, acting solely as a 375-lb. single-expansion nonreheating plant, it could produce a net kw-hr. for 15,100 B. t. u. in the fuel and as a 1200 lb. compound reheating plant, it could produce a net kw-hr. for 13,600 B. t. u. These figures show the advance in heat economy that modern developments in steam engineering have made possible and the advantage which the very high-pressure reheat cycle possesses over the more conventional design. The actual plant performance will depend among other things upon the character of the load which it is found possible to put on Weymouth Station and the relative proportion of high and normal pressure equipment that may be operated.

CONTENTS

In common with many of the other public service companies serving our larger communities, The Edison Electric Illuminating Company of Boston has found its existing power stations and sites developed to their economical limits. Faced with a rapidly growing demand for service and with a broad vision into the future, it is constructing, on an entirely new site, the initial development of a station expected to have an ultimate capacity of approximately 300,000 kw.

The scope of this paper is limited to a brief description of this station and its equipment, with an interspersed discussion of such engineering features as are thought to be of more timely interest.

Presented at the Annual Convention of the A. I. E. E., Swampscott, Mass., June 26-29, 1923.

General Features

The selected site on the Fore River in Weymouth contains about 63 acres. It is on deep water, readily accessible by large ocean going coal carriers, and has all other advantages necessary to give entire freedom in the design of a large modern station.

Fig. 1 shows the general cross-section of the station. The turbine room is to be located adjacent to the water front so that the condensing water tunnels will be direct and short. These tunnels are designed to give the same ease of flow as though they were to serve hydraulic turbines. The boiler room adjoins the turbine room on the land side and lies between the latter and the isolated building for the busses and electrical control.

The initial main generating equipment will consist of two 32,000-kw. turbines each driving a main 30,000-

kw. generator and a 2000-kw. auxiliary generator direct-connected to the shaft of the main generator. These units will be supplied with steam at a nominal pressure of 375 lb. and a total temperature of 700 deg. fahr. There will also be one 2500-kw. high back pressure turbo-generator taking steam up to 1200 lb. pressure and exhausting into the 375-lb. system. All station auxiliaries are to be driven by alternating-current motors.

The boiler installation will include three boilers each containing 19,743 sq. ft. of heating surface, with additional superheater and economizer surface, designed for 375-lb. working pressure. There will also be one boiler, of approximately the same heating surface, which will be designed to operate at a maximum of

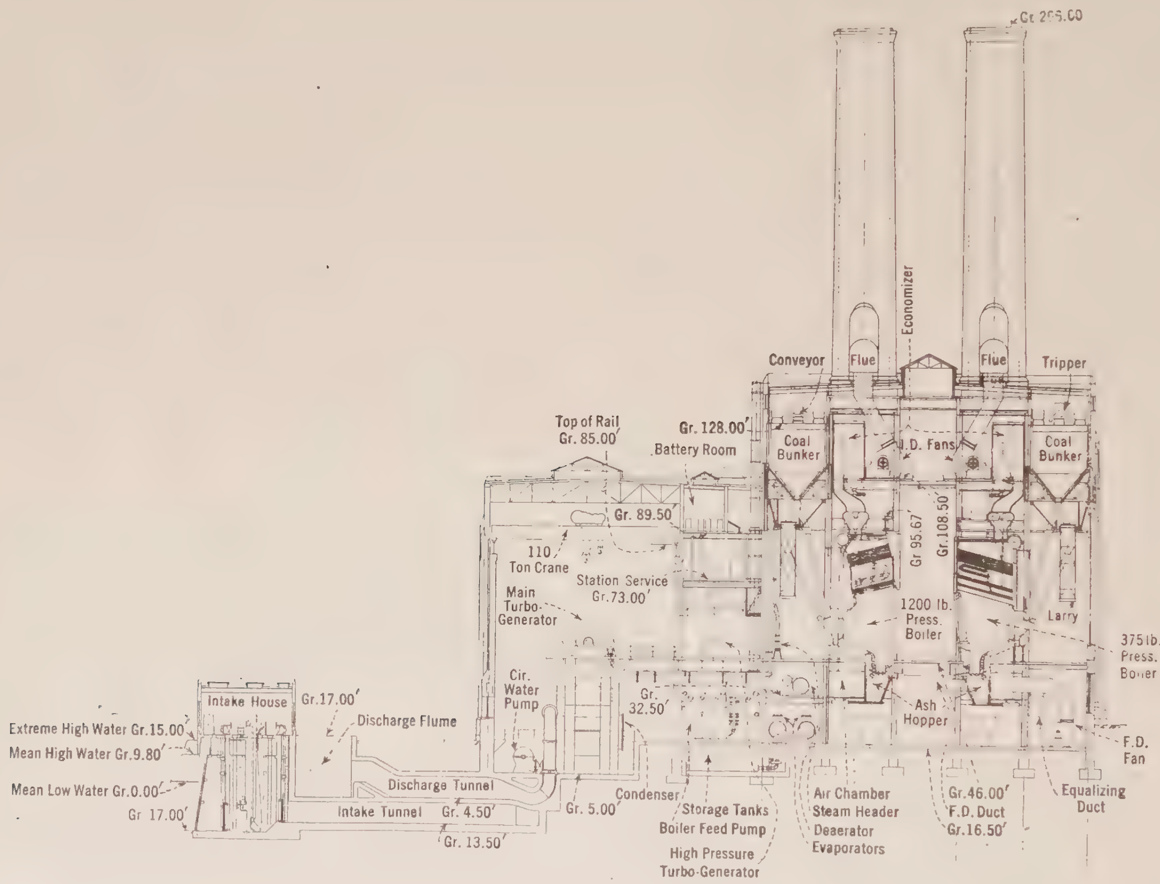

Fig. 1—Cross-Section, Weymouth Station

1200 lb. It will likewise be provided with a superheater and an economizer, and also a steam reheater to restore the temperature of the exhaust steam from the high back pressure turbine to 700 deg. before it passes into the 375-lb. system. All boilers will be fired with underfeed stokers.

The coal handling equipment will consist of two electric unloading towers, a traveling bridge spanning the storage pile, and a system of belt conveyors for transporting the coal to or from the main storage or directly from the unloading towers to the station bunkers. The conveyor for delivering the coal to the station will be about 700 ft. in length. The traveling bridge is to carry a man trolley with bucket for reclaiming from the storage pile. A Bradford breaker will be used for crushing the coal on its way to the station.

Current will be generated at 14,000 volts, three phase, 60 cycles. It will be distributed from the station through underground circuits partly at generator voltage and partly at 25,000 volts through an adjacent outdoor transformer substation. Future transmission by overhead lines at 115,000 volts will also be provided for. The bus and switching arrangement is described later in this paper.

Selection of Steam Conditions

The important bearing which the operating steam pressure and temperature have upon the possible maximum fuel economy of a station naturally called for an extended study of these features before reaching a decision in regard to them. When suitable economizers are employed the influence of steam pressure and temperature upon the efficiency of steam generation is negligible, but the influence of these factors upon the efficiency with which the heat in the steam can be utilized is in any case of definite importance.

The selection of the temperature at which the steam should be supplied to the turbine is almost entirely a problem of materials, as the beneficial effect of superheat, although largely indirect, continues in worth-

while proportion up to the maximum temperature which our engineering materials will properly withstand. In some isolated instances, European engineers have employed temperatures as high as 750 deg. to 800 deg. fahr. and in America temperatures as high as 725 deg. fahr. have been chosen by some designers. In considering this matter for the Weymouth Station it seemed best to place the nominal limit at 700 deg. fahr. It however appeared entirely practicable to employ this limiting temperature regardless of the pressure adopted.

Decision as to the most advantageous steam pressure could not be reached without a much more involved study, especially in view of the general lack of experience with the higher pressures and a decided variation in prophecy as to the net advantage to be derived through their use.

It was apparent that this study, to be complete, would have to cover the following considerations:

1. The improvement in economy of heat utilization made theoretically possible by increased steam pressure.
2. The extent to which available equipment could be expected to take advantage of the theoretical possibilities.
3. The probable effect of increased pressure upon reliability of operation and its flexibility in meeting anticipated load conditions with high over-all economy.
4. Freedom in taking advantage of future changes in the art.
5. The economic balance of carrying charges and operating costs over a long period.

The development of one part of the study to determine the effect of the higher pressures upon improved economy is illustrated by the curves in Fig. 2. All of these curves have absolute steam pressure as their abscissae.

Curve No. 1 shows the total heat in one pound of steam at a uniform temperature of 700 deg. fahr. above 79 deg. fahr., which is the temperature corresponding to one inch absolute pressure. It will be noted that the total heat shows a decrease with increasing pressure.

Curve No. 2 shows the heat remaining in the steam after perfect adiabatic expansion from the stated initial conditions to a pressure of 1 in. absolute. The vertical distance between this curve and curve No. 1 accordingly represents the B. t. u. per pound of steam theoretically available for doing work.

Curve No. 3 is a plotting of the available heat as a percentage of the total initial heat shown by curve No. 1 and represents the efficiency of the Rankine cycle at varying pressure. Its upwardly convex curvature indicates how the rate of increase in theoretical efficiency diminishes with increasing pressure.

Curve No. 4 shows the best efficiency at present to be expected of turbo-generators in converting the available heat, as shown by Curve No. 3, into useful electrical energy. In determining this curve the unit is credited with all heat recovered in the condensate by bleeding at two stages.

Curve No. 5 is the product of Curves No. 3 and No. 4 and indicates, for the different pressures, the percentage of the total initial heat in the steam which would be actually converted into electrical energy or returned to the boiler in the condensate. It will be noted that this curve takes the shape of a dome with its highest point corresponding to a steam pressure of about 600 lb. absolute.

If steam turbines could be constructed which would be equally efficient in transforming the available heat energy into useful work under all of initial steam pressure conditions, Curve No. 3 would indicate that the over-all thermal efficiency would increase with the pressure throughout the entire range considered. The most important factors which act to decrease the turbine efficiency at higher steam pressure are the increased gland and interstage leakage losses and, more particularly, the increased steam friction occasioned by the entrained water after the dew point has been reached. This lowered efficiency is particularly marked where the maximum permissible total temperature causes the higher pressures to be accompanied by diminished super heat, thus advancing the dew point to an earlier stage. The recognized method of meeting this difficulty and thus permitting the superior possibilities of higher steam pressures to be realized, is to interrupt the expansion of the steam at some intermediate pressure and restore its temperature by reheating before the expansion is continued. This may be accomplished either by employing two independent turbines, one exhausting to the other through the reheater, or by returning the reheated steam to the lower stages of the same machine from which it was extracted. The design of the Weymouth Station makes provision for employing the first of these two methods using a maximum pressure of 1200 lb.

In order that the reheater may be required to add superheat only to the steam, it is necessary that the exhaust from the high-pressure turbine be dry. The amount of energy that may be extracted from a given weight of steam between an initial condition of about 1000 lb. at 700 deg. and the dry saturated condition is only a fraction of that which can be utilized by its further expansion to vacuum after reheating. This condition permits the use of large standard design turbine units for the second expansion stage of the cycle. Thermodynamically it makes little difference in the cycle efficiency at what pressure the steam is reheated, or, indeed, if it is reheated at all. In practical operation, there is a certain pressure at reheat which gives the best combined efficiency of the two turbines working in series, but the efficiency at this pressure does not appear to be a great deal higher than at other pressures rather widely different from it. Of greater importance are the mechanical problems connected with rehandling the steam and the higher the pressure, within limits, the

easier these become. For the particular situation under discussion, it was desirable to have the lower pressure portion of the plant able to function as a complete and highly economical station, so that the same considerations which control the selection of an initial pressure for the single expansion cycle were allowed to govern the choice of a reheat pressure in this case. Although it appears from Curve 5 of Fig. 2, that about 600 lb. is the most efficient pressure for a single expansion unit, cost influences make a somewhat lower pressure more economical to use. For Weymouth Station the pressure selected is 375 lb.

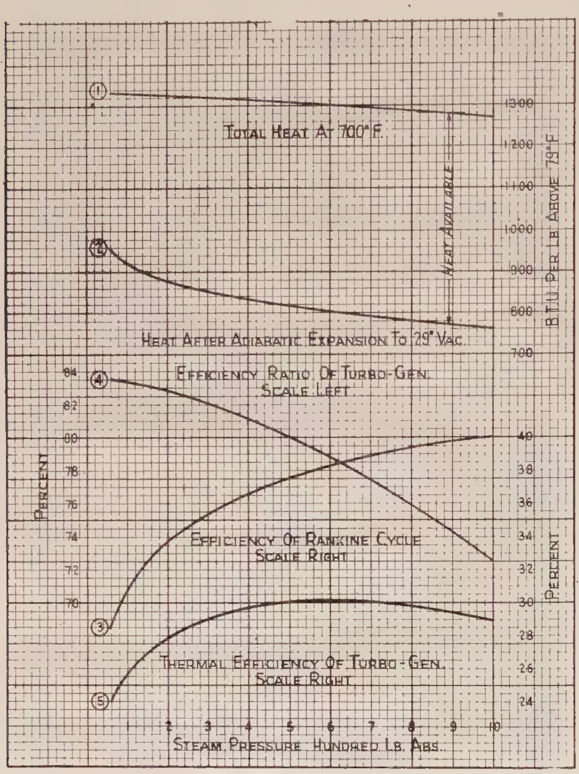

Fig. 2—Effect of Steam Pressure on Turbine Thermal Efficiency

High Pressure Installation

The high-pressure boilers will normally deliver steam at approximately 1000 lb. pressure and 700 deg. total temperature, corresponding to about 153 deg. of superheat. The entire steam output of each boiler, which under the usual operating conditions will be about 110,000 lb. per hour, will pass through a simple three-stage turbo-generator where it will be expanded down to a pressure of 375 lb. The steam will then be reheated to 700 deg. in a reheater installed in the same boiler setting, and finally be discharged into the 350-lb. header serving the main turbines. It may be noted from the quantity of steam passing through each of the high-pressure turbines that three such boiler-turbine units will be required to supply one of the main 32,000-kw. turbines at the higher loads. Operating under the conditions outlined each of the high-pressure turbines will generate about 2000 kw. Thus, a total of 6000 kw. will be generated in reducing the pressure of the steam required by one of the main units.

The high-pressure boilers will have tubes 2 inches outside diameter and 15 feet long. The tubes will be arranged in two banks with sufficient space between for the superheater and reheater. The drum will be a hollow steel forging 48 inches inside diameter with walls 4 inches thick. In order to maintain suitable drum strength the tubes and nipples, which commonly enter the drum in lines parallel with its axis are turned in pairs through an angle of 90 deg. so that the two enter the drum on a common circumference. Fig. 3 shows a cross-section of this boiler.

The generator of the pressure reducing units rated at 3000 kv-a. is to be of the induction type, if a suitable design can be worked out. This would avoid the necessity of separate excitation and careful synchronizing when being placed in service.

There are many new problems involved in the design, construction and operation of this high-pressure and reheating installation, but their nature is such that their solution may be confidently expected. It is recognized, however, that a considerable amount of development work will have to be done. It has therefore been decided to employ proven types of equipment for the larger part of the initial installation, confining the use of equipment which is as yet lacking commercial demonstration to a comparatively small supplemental installation of one high-pressure boiler with its turbine unit. This installation will afford an opportunity to demonstrate the general practicability of using very high-pressure steam in a re-heat cycle.

The ratio of high-pressure equipment and normal pressure equipment to be installed in the future will depend upon the results obtained from this initial installation and upon the experiences of others who are working along similar lines, or who are employing other methods for the utilization of high-pressure steam and the re-heat cycle.

Any estimate of the improvement in heat utilization to be expected from the use of very high steam pressure, is necessarily based on assumed properties of steam obtained by extrapolation of existing steam tables and diagrams, which may be subject to some correction. The calculated savings are so large, however, that it is felt that any probable error in these assumptions as to the properties of steam will have a relatively unimportant bearing.

Boiler Plant and Feed Water Heating

The normal pressure boilers, which are to deliver steam at 375 lb. and a final temperature of 700 deg. will be of the cross drum design, 48 tubes wide and 17 tubes high, with the superheaters between the tube banks. The exit gases will be further cooled by straight steel tube economizers which, with the induced draft fans, will be located above the boilers. The furnace arrange-

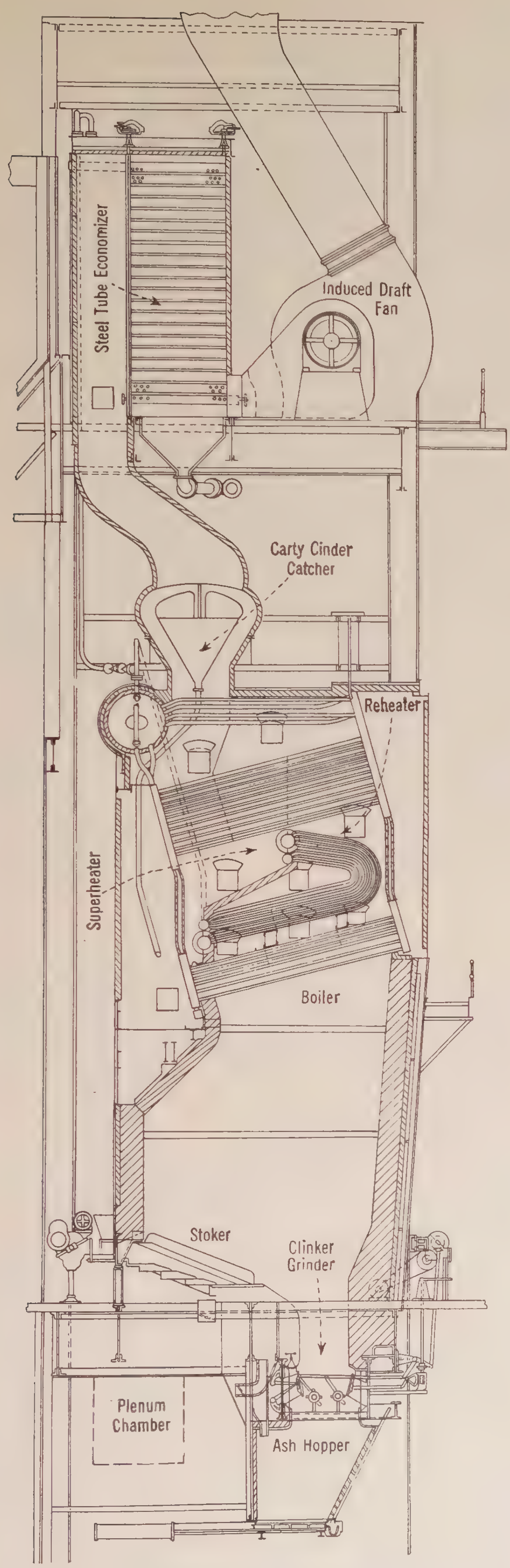

FIG. 3—SECTION OF 1200-LB. BOILER

ment provides for firing from the low end of the boilers. The stokers are to be of the underfeed type, with clinker grinders, there being 16 retorts per boiler. The boilers will be set with the bottom of the uptake headers 25 feet above the firing floor. They will be arranged in parallel rows with the uptake ends facing a common center aisle from which all firing operations will be controlled. The stokers, which will thus be in the side aisles, will be supplied with coal from overhead longitudinal bunkers. This general arrangement of the boiler room is the same as that of the newer portion of the Edison Company's "L Street" Station, where it has proved highly satisfactory. It provides well lighted, clean and cool working quarters for boiler room operators and locates the stokers where abundant side light and ventilation are readily obtainable.

Except for the necessary modification in details, the boiler designed for operation at 1000 lb. pressure, and previously described, will be installed in accordance with the same general plan employed for the lower pressure boilers. The stoker and furnace installation will be practically the same and no attempt is to be made to isolate this installation.

Make-up water is to be provided by evaporators and the entire supply will be deaerated.

Economizers with a heating surface equivalent to about 55 per cent of the boiler surface were chosen. This selection was preceded by a study of the following influential factors:

1. The temperature at which the feed water should leave the bleeder heaters and enter the economizers.
2. The most advantageous division of the total heating surface between the boiler and the economizer.

The capacity of the feed water to absorb heat is theoretically limited by the range between two fixed temperatures,—that of the condensate and that of the saturated steam in the boiler. The practicable range of heating is, of course, somewhat narrower. The heat consumption of the main turbine, when credited with all heat returned to the system, is unquestionably the lowest when all of the heating is done by extracted steam. On the other hand, the efficiency of the boiler plant is highest when all of the heating is done in the economizer. The best over-all plant efficiency must therefore lie in some compromise between these opposing considerations. The calculations made for the Weymouth Station indicated that the most advantageous temperature to change the method of heating was between 210 deg. and 220 deg. fahr. Practically considered this is a most desirable temperature, also, for it avoids the use of superheated steam in the extraction heaters, diminishes the possibility of external corrosion of economizers and permits adequate deaeration of the feed water.

Considering the boiler and economizer in common, it is evident that for heating the water through a given total temperature range, and with a given outlet gas temperature, there will be less total heating surface

required as the proportion arranged as counterflow economizer surface is increased. The relative cost of the two kinds of surface, however, exerts an opposing influence and necessitates a compromise. As to the boiler, its width is largely determined by the number of stoker retorts required, so its heating surface varies with its height. For the Weymouth Station the various considerations indicated that a boiler 17 tubes high and with 55 per cent additional economizer surface would provide the most satisfactory proportion, and that the resulting economy would justify the installation of this total amount of surface.

Decision to fire the boilers with stokers was reached only after a very careful study of the relative merits of using pulverized coal. The conditions surrounding this problem for the Weymouth Station were such that the probable savings in fuel through the use of powdered coal represented a relatively low percentage of the total fuel cost. This estimated saving was further reduced by the additional carrying charges to a margin which was too narrow to clearly call for the use of the powdered coal system. It was accordingly decided to adhere to the present practise of the Edison Company and employ stokers, at least for the initial boiler installation.

Auxiliary Drive

All of the normally operating station auxiliaries are to be electrically driven, using alternating-current motors throughout. Motors of 25 h. p. and less will, in general, be served at 550 volts, and those of greater capacity at 2300 volts. Any necessary speed regulation is to be obtained through the use of brush shifting and slip-ring motors.

Power for all auxiliaries upon which the continuity of operation of the main units depends, will be supplied from auxiliary generators driven by the main turbines through direct connection to the shafts of the main generators. These auxiliary alternators will have a rating of 2500 kv-a. and will generate at 2300 volts, 3 phase. They will be mechanically in phase with the main generators so that although they will normally operate independently, they may be connected to the main bus through suitable transformers when desired. In starting up a main unit all of the auxiliaries will be started from the main bus but after the unit is in operation the important auxiliaries will be transferred to the auxiliary bus of that unit and thus be supplied from the auxiliary generator independently of the main circuits. The less important auxiliaries will be regularly operated from a 2300-volt bus fed through transformers from the main bus. A separate steam driven auxiliary turbo-generator will be provided to permit starting the station from cold in emergency.

Each generator will be excited by a 175-kw. motor generator set, consisting of a 2300-volt induction motor and a 250-volt direct-current generator. This set will be operated from the direct-connected auxiliary generator. A spare motor generator exciter and also a spare steam driven exciter are to be installed for emergency excitation and for battery charging. A storage battery will float on the exciter bus. The 2300-volt auxiliary generators will have direct-connected exciters but in an emergency may be excited from the 250-volt busses.

The auxiliary generators, being driven by the main turbines, will produce electrical energy with the highest obtainable economy, practically equal to that of the main units themselves. It is therefore expected that the use of this system will permit the attainment of higher plant efficiency with greater security, than would be possible with any other method of auxiliary power supply which presented itself.

The complete avoidance of auxiliary exhaust steam permits the preliminary heating of the feed water to be accomplished entirely by multi-stage bleeding of the main turbine. It is well recognized that this method of heating results in greater efficiency than by the use of exhaust steam from individual auxiliary turbines, "house turbines," or any combination of them. In most other possible arrangements for heating the feed water entirely by bleeding the main units the supply of auxiliary power must be taken from the bus and thus be subject to the effects of external electrical disturbances. Even the use of separate house turbines usually involves a connection with the main bus, either directly, with its attendant hazard to continuity of service, or through a motor generator set with attendant lowered efficiency,—this connection being required to secure the proper feed water temperature while carrying an auxiliary load which does not necessarily bear a direct relation to the feed heating requirements.

Switching Arrangement

Figs. 4 and 5 show in diagram a plan and cross-section of the isolated switch house as it is expected to develop, consisting of four stories and a basement. All incoming and outgoing circuits enter or leave through the cable room in the basement.

In the layout of the cable room the following have been the guiding principles:

Proper segregation of the cables in the ducts.

Facility for taking any feeder circuit into any outgoing duct line without the need of further crossovers in outside manholes.

Means for testing any cable at any time at suitable high voltage, and for complete protection of men working on cables, through potential indicating and grounding devices.

Suitable space and handling facilities for cables.

The three floors above are occupied by the busses, switch gear and reactors, each phase being isolated on a separate floor. Fig. 5 shows a different equipment section on each floor,—on the first floor is represented a feeder section, on the second a generator section and on the third a bus tie section.

On the fourth floor are located the oil circuit breaker and disconnecting switch operating mechanisms, which

are interlocked to prevent the wrong sequence of operation. The switchboard room adjoins the mechanism room on the same floor, making a compact and convenient operating arrangement. On the third floor directly under the switchboard there is a conduit room to permit flexibility in adapting control circuits to future growth.

The switch house structure is subdivided by suitable longitudinal and cross partition walls so that each bus section is in a room by itself. Conduit is run in floors and kept out of electrical structures wherever possible. Metallic reinforcement of concrete electrical structures has also been avoided as far as practicable and where reinforcing is essential it is either discontinuous or solidly grounded, so that a high-resistance ground passing insufficient current to open the circuit will not cause heating of the reinforcement and disintegration of the concrete.

The contemplated arrangement of the 14,000-volt main power circuits may be seen from the diagram in Fig. 6. A double-ring bus is planned, in conjunction with a single transfer bus. The two-ring busses will be sectionalized with current-limiting reactors between sections. Each section will be fed by two generators. It will be possible by use of the transfer bus to interconnect any two of the sections, thus permitting complete flexibility of operation. For the initial development only one bus section will be necessary, which will be operated simply as a double bus.

The connection of all generator and feeder circuits to the bus is to be through two oil circuit breakers in series so that there may be double assurance of ability to open the circuit under any emergency condition. This object may also be attained by the use of group busses if the capacity of the individual circuits is insufficient to warrant the expense of the extra breakers that would otherwise be required. The oil circuit breakers for use on feeders and for bus sectionalizing are guaranteed to rupture 34,500 amperes at 15,000 volts. Those on generators and on large capacity

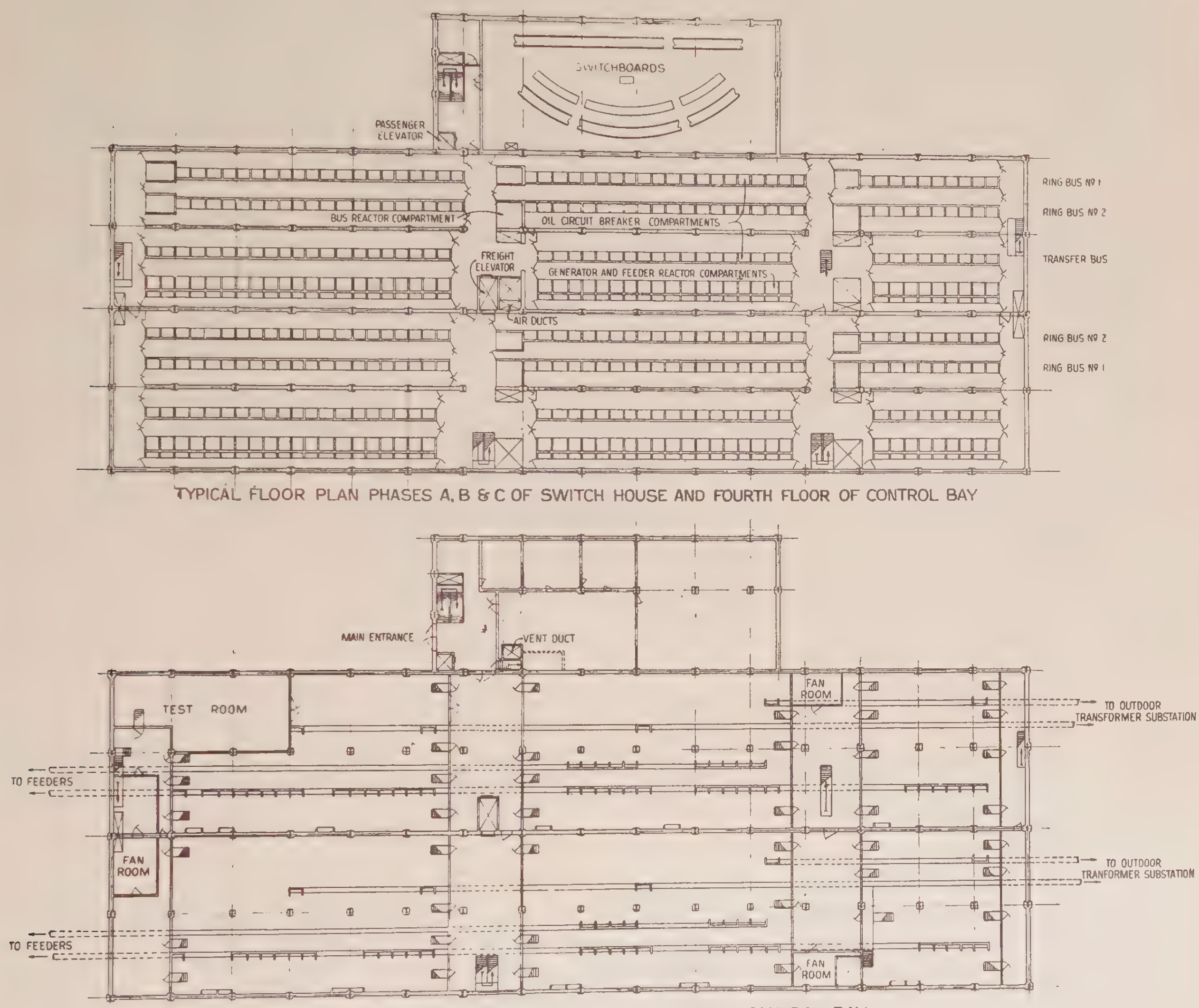

Fig. 4—Plan of Switch House

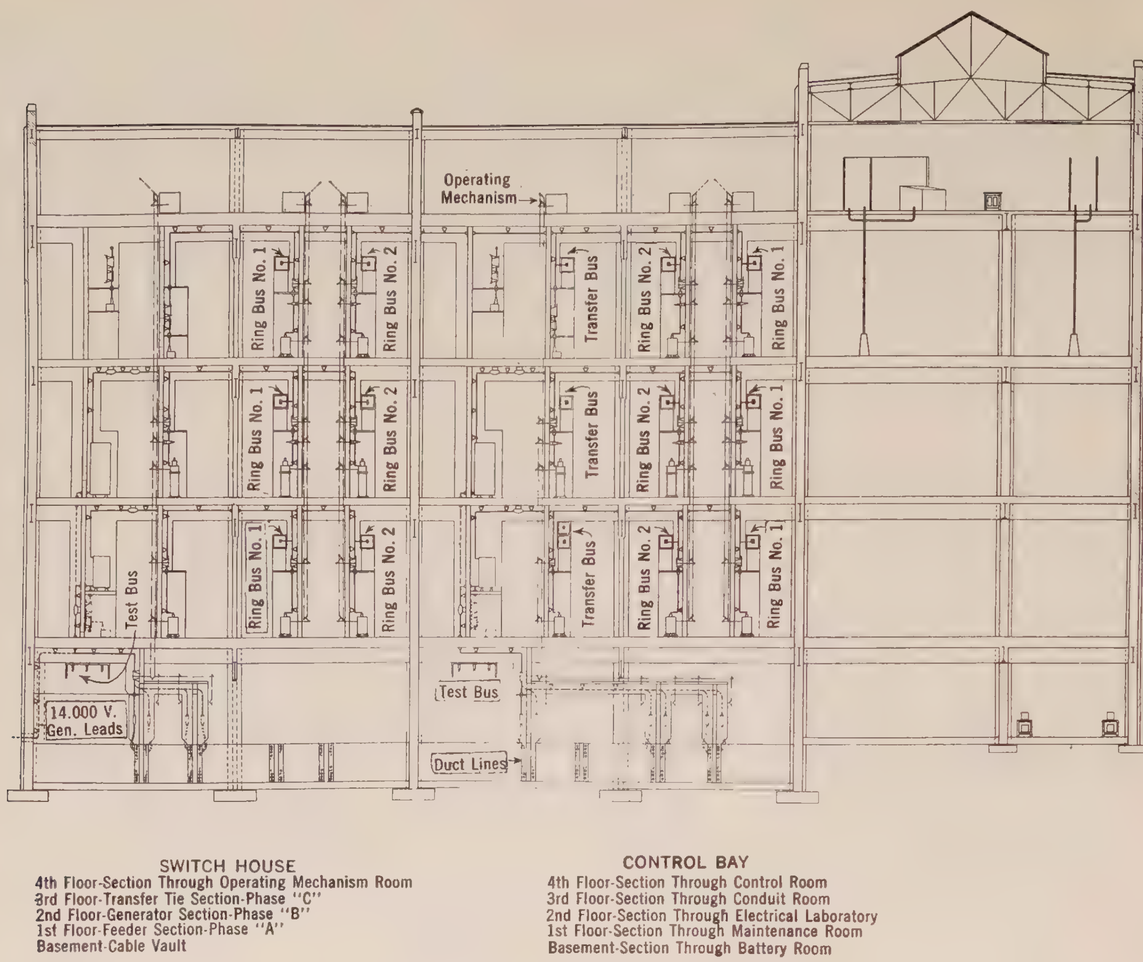

Fig. 5—Cross-Section of Switch House

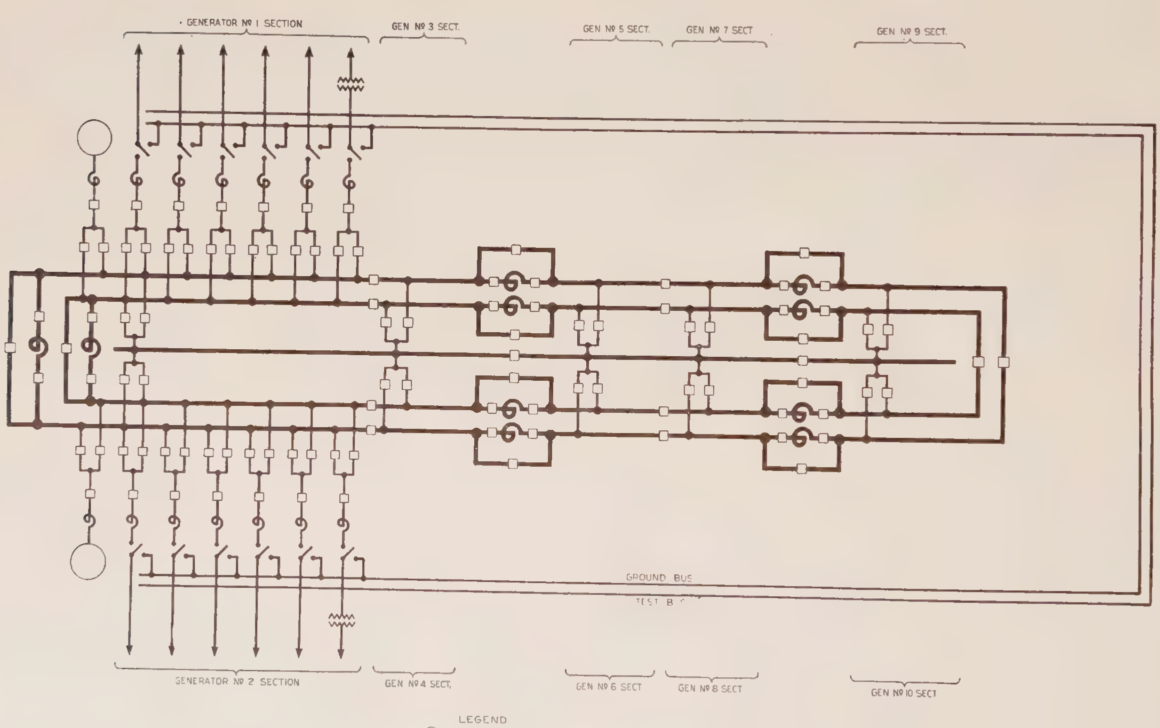

Fig. 6—Main Switching Connections

transformer circuits which may connect with other power systems are guaranteed to rupture 58,000 amperes at this same potential.

The generators and their cable connections to the busses will be protected by balanced relays arranged to automatically disconnect any unit from the bus in the event of a ground or short circuit on the machine side of the circuit breaker. The generator leads are to be single-conductor cables carried on insulators from the machines to the switch house, through closed corridors. No cables carrying a higher potential than 2300 volts will be carried in ducts within the station.

On account of the relatively low capacity of the generators which are to be driven by the 1200-lb. pressure turbines, the expense of providing the necessary bay between the boiler room and turbine room. Truck type switch gear will be used.

Plant Efficiency

In what has gone before the discussion has centered for the most part around the efficiency of particular apparatus, conditions or methods. Of even greater interest to engineers in general is the efficiency of the whole plant as being indicative of the care and skill with which the various components have been proportioned and assembled, and the necessary compromises made between conflicting requirements.

It has been shown that in what, for purposes of differentiation, has come to be called the "Normal Pressure" part of Weymouth Station, steam pressures comparable with the highest now employed in America

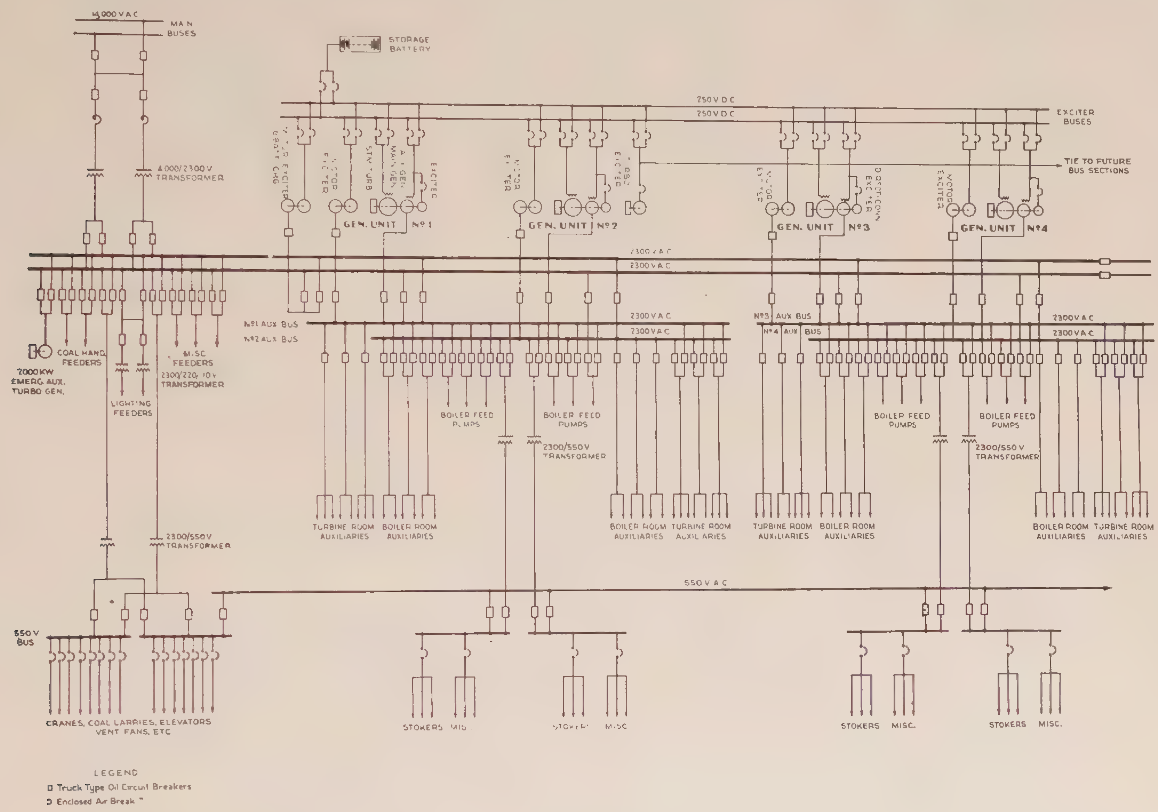

Fig. 7—Auxiliary Switching Connections

switching equipment and building space, for their direct connection to the main bus is not warranted. It is planned, therefore, to connect each group of three of these units to a separate bus through low-capacity oil circuit breakers. The group bus, will in turn, be connected to the main bus in about the same manner as a feeder.

A wiring diagram of the system for driving the station auxiliaries is given in Fig. 7. The auxiliary generators will be controlled from the main switchboard and the operator there will be responsible for keeping the 2300-volt busses constantly energized. The 2300-volt busses will be located in separate substations, one for each two units, to be provided in the auxiliary are to be used. In addition pressures higher than any that have been used heretofore for similar purposes are to be thoroughly tried out in conjunction with the reheat cycle.

Feed water heating is to be accomplished both by steam extraction from the main turbines and by the use of economizers. To obtain the maximum of benefit from the steam extraction method of heating motor driven auxiliaries only are to be used, supplied with power from a most efficient direct-connected auxiliary alternator. The auxiliary apparatus itself has been selected with a view to obtain the highest efficiency in both the driving and driven members.

Fig. 8 shows, in the upper diagram, an analysis of

the performance which could theoretically be realized in the operation of the normal pressure (375 lb.) portion of the station of the design as described. The lower diagram shows a similar analysis for such a station operating exclusively on the reheat cycle, with the entire steam supply generated at 1000 lb. Both diagrams are based upon ideal operating conditions, *i. e.*—a constant station load of such amount and energy, which is equivalent to 15,100 B. t. u. per kw-hr. net generated, or approximately 1.05 lb. of coal of a heat value of 14,400 B. t. u. per lb.—while the corresponding figures for the high-pressure reheat plant are 25.1 per cent, 13,600 B. t. u. per kw-hr. and approximately 0.945 lb. of coal.

They above calculated results represent only the ultimate possibilities under ideal load conditions. It

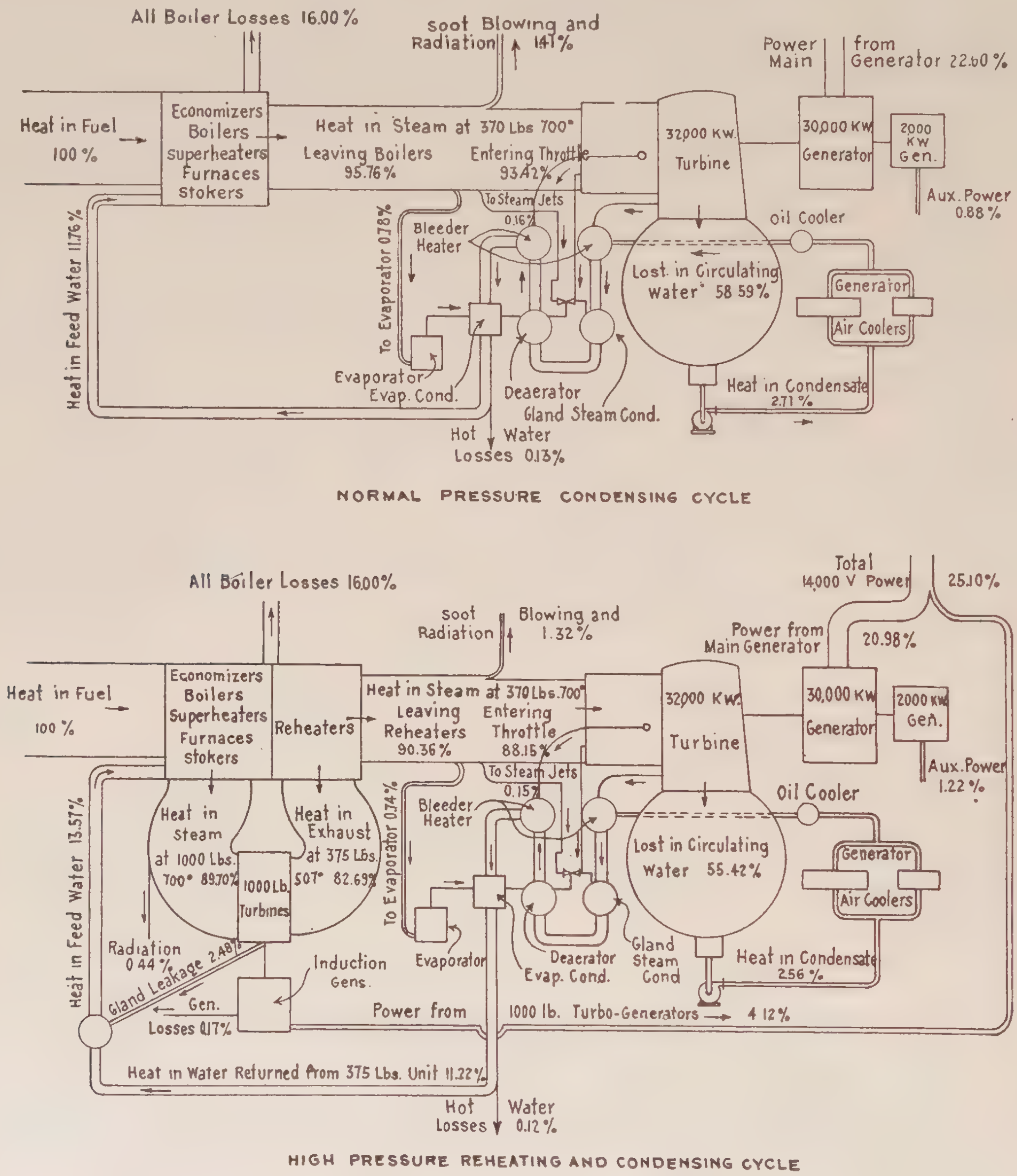

Fig. 8—Heat Balance Diagram

character as would permit the main units to operate at their point of best efficiency and at 100 per cent load factor. The estimated efficiency of each individual piece of equipment is that guaranteed by the manufacturer.

From these diagrams it will be observed that the normal pressure straight condensing plant will transform 22.6 per cent of the heat in the fuel into electric is, of course, impossible to predict what the results of actual operation will be as this will be influenced considerably by the extent to which a constant base load can be allocated to the Weymouth Station and the extent to which it is found advisable to employ the high-pressure equipment in making future extensions to the station.

The Quality of Incandescent Lamps

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Review of the Subject.—*The new specifications for incandescent lamps determine their quality in terms of life to burnout at a specified mean efficiency. Formerly it was measured by the life to 80 per cent. of initial value. The new tests, therefore, conform more nearly to the actual practise in the use of tungsten filament lamps, as many of these lamps are above 80 per cent at time of burnout.*

The data on carbon lamps in the paper are based on a life exponent originally determined by Mr. Howell, one of the authors of this paper. Curves showing the relation between life, efficiency and candle power was given by him in a paper presented before the Institute on April 10, 1888. Practically the same life-candle power relation has been found to apply to the GEM, tantalum and tungsten filament lamps. Nowadays the exponent used is that applying to the life-efficiency relation and is different for each kind of filament as they have different candle power-efficiency relations. All data are based on commercial ratings and guarantees.

The quality of tungsten filament lamps has greatly improved since their commercial introduction in 1907 as is shown by the fact that the 40-watt vacuum lamp is now over eight times as good as then.

There is a difference in the present relative quality of the various sizes of tungsten filament lamps. The 10-watt vacuum lamp, if operated at 10 mean lumens per watt, would live 190 hours and the 1000 watt gas-filled lamp 35,000 hours. The lives of other sizes of lamps at this efficiency is between these two extremes.

There has been an enormous improvement since Edison's first commercial carbon lamp of 1880. It is estimated that if the present 40-watt tungsten filament lamp were made for the same mean efficiency as the 1880 lamp, the tungsten filament lamp should have a life of over a hundred and fifty thousand years. And this does not include the enormous improvement in the larger sizes of lamps due to Dr. Langmuir's invention of the gas-filled lamp. Owing to these enormous differences, the other term of quality measurement, indicating the mean efficiency for a given life, is therefore used to show the improvements since 1880. A table gives these data in chronological order.

It is estimated that in 1880 about 50 lumen-hours of light were obtained for one cent, covering the cost of current and lamp renewals. The amount now obtainable is very much greater, due to lamp improvements, reduction in their prices and reduction in rates for current. The public has utilized these by using more light. With the present 40-watt tungsten filament lamps and with current at the present approximate general average rate of 4½ cents kw-hr., 1700 lumen-hours can be had for one cent. It is impossible to show what part of this actual increase is due to lamp improvements except to indicate what would have been obtainable with one factor without the other. Thus had there been no rate reduction, 432 lumen-hours would now be had due to actual lamp improvements. Without the lamp improvements 190 lumen-hours would now be had due to the reduction in the general average rate. To indicate the gain due to Dr. Langmuir's invention of the gas-filled lamp, in which the high wattage sizes are the most efficient, 3820 lumen-hours can be had with the 1000 watt lamp at 4½ cents per kw-hr.

About half a billion dollars were spent in the United States in 1922 for current used for lighting. If the same amount of light were produced by the original 1880 bamboo carbon lamp, the cost would have been increased 3½ billion dollars requiring about fifty billion extra tons of coal, equal to about ten per cent of the total coal production in the United States.

THE purpose of this paper is to show the improvements have been made in incandescent electric lamps since they first became commercially available.

Quality is the term used by incandescent lamp engineers in connection with the relative excellence of lamps. The two main factors which determine quality are efficiency and life. With a given quality these two factors bear a reciprocal relation to each other, that is, the life of a lamp can be increased but at a sacrifice of efficiency, and vice versa.

Attention is called to the fact that Mr. Howell, one of the authors of this paper, presented before the Institute on April 10, 1888, a paper entitled "The Maximum Efficiency of Incandescent Lamps". This paper gave, for the first time, data on the relation between the life and efficiency of incandescent lamps. Occasional reference to this paper will be made.

An improvement in quality might be reflected as an increase in efficiency or in life, without a reduction of the other factor. Quality, therefore, may be measured either in terms of efficiency for a given life, or in terms of hours life for a given efficiency. In the 1888 paper the latter term was used, the quality of lamps being stated as "The life they will give when burned at a given efficiency."

The quality measure is useful to lamp engineers in determining the usefulness of suggested improvements in lamps, in comparing the performance of different types of lamps and in maintaining the product up to the highest possible standard.

Standard Specifications for Determining Lamp Quality

The Bureau of Standards at Washington, D. C., have for some time established specifications on lamps for use by the various departments of the United States Government. These specifications were established by them after conference with manufacturers and engineers. The present specifications are different from those in use up to about two years ago.

The difference between the present and previous specifications can perhaps best be explained by quoting the introductory statement of Circular 13 of the Bureau of Standards:

"The most notable of these changes is the abandonment of the long-established provision that the life of test lamps shall be considered as ended when the candle power has fallen to 80 per cent of the initial value. The specification of such an end point is convenient and

Presented at the Annual Convention of the A. I. E. E., Swampscott, Mass., June 26-29, 1923.

reasonable in the testing of carbon lamps, because those lamps will often burn for a long period after they have become so blackened that they should not be continued in use. In tungsten lamps, however, means have been found to prevent excessive blackening of the bulbs, so that the lamps normally burn out before their efficiency has fallen enough to justify replacing them. The new tests will, therefore, be based on the total life to the time of burnout, thus conforming more nearly to actual practise in the use of lamps."

"The performance of the lamp throughout its life will also be taken into account through — the evaluation of life-test results on the basis of average efficiency throughout life, instead of the initial efficiency."

It will be noted that the inherent quality of lamps is now measured by the number of hours life to burnout at a given average efficiency throughout life. Lamps may be operated on test at an efficiency that will make the duration of the test about 500 hours. For purposes of comparison of different lots of each size of lamp and for a permanent historical basis of record, mean efficiencies are given in the specifications for each lamp, which efficiencies were originally based on an average life of 500 hours.

Basis of Data

In Mr. Howell's 1888 paper, a curve was shown indicating the relation between the life and efficiency of carbon lamps, which at that time had untreated filaments. This curve was based on the author's calculations, obtained from the tests of many lamps during a period of over five years, that the life of lamps varied inversely as the 3.65 power of the candle power. This life-candle power exponent however was not given in the paper. In the intervening years, even with the tests of many more lamps, this exponent has remained unchanged. It has even been found that the same life-candle power exponent applies to the treated carbon, the Gem (metallized carbon) and practically to the tantalum and tungsten filament lamps.

Nowadays it is customary to make calculations on the basis of the life efficiency exponent. This exponent varies with the different lamps as the candle power-efficiency curve is different for each kind of filament. The life-efficiency exponents used in the calculations of the data given herein are as follows:

5.5 for the untreated carbon filament lamp
5.8 for the treated carbon filament lamp
5.8 for the Gem (metallized carbon) lamp
6.2 for the tantalum lamp
6.7 for the tungsten filament lamp

The exponent for tungsten filament lamps has been considered to be different for the different sizes of lamps, but it is now believed by many that the figure 6.7 applies to all sizes, so this figure is used herein.

Improvement in Quality of Tungsten Filament Lamps

Limitation of space prevents giving data showing the improvement in all the different sizes of tungsten filament lamps from their commercial introduction to date. The most important of the vacuum lamps is the 40-watt, 115-volt size. The suggested standard comparison efficiency given in the specifications for this lamp is 9.9 mean lumens per watt. The actual life obtained at this mean efficiency, based on the commercial ratings in effect at various times from the introduction of this size of lamp in 1907 to date, is as follows:

TABLE I.
QUALITY OF 40-WATT 115-VOLT VACUUM TUNGSTEN FILAMENT LAMP, 1907-1923

Date	Initial efficiency	Hours life to burnout	Spherical reduction factor	Mean Efficiency in percent of Initial	Inherent Quality: Hours life to burnout at 9.9 mean L-P-W
Nov. 1907	1.25 w-p-h-c-p	800	78%	85%	63
Apr. 1910	*1.23 do	1000	78%	85%	78
Oct. 1912	1.17 do	1000	78%	86%	120
Jan. 1914	1.10 do	1000	78%	87%	196
Oct. 1914	1.03 do	1000	78%	88%	327
May 1917	1.35 w-p-s-c-p	1000	——	87%	261
July 1917	1.33 do	1000	——	88%	312
Aug. 1918	1.36 do	1000	——	87%	250
Apr. 1920	1.35 do	1000	——	87%	261
May 1921	9.9 l-p-w	1000	——	89%	458
Oct. 1921	10.1 do	1000	——	90%	564
May 1922	10.1 do	1000	——	89%	524
May 1923	10.1 do	1000	——	89%	524

*The International candle in use since April 1910 is 1.6 per cent less than the standard used prior to that date.

It will be seen that a great improvement in the quality of this lamp has been made since its introduction sixteen years ago; in fact the quality then was but 12 per cent of what it is now. Due to war conditions there were slumps, but the lamp is now about twice as good as it was in 1914. These data, derived from commercial ratings, show average figures—there are of course occasional fluctuations.

Difference in Relative Quality Between Various Sizes of Tungsten Filament Lamps

A difference in relative quality between the various sizes of lamps is indicated by the difference in their rated initial efficiency. Table II shows the present difference in relative quality between the various standard sizes of 115-volt tungsten filament lamps as determined from their commercial ratings.

It is impractical to chart the relative quality given in the above table in terms of hours life at a given efficiency. A chart, Fig. 1, has therefore been prepared showing the present relative quality in terms of the mean efficiencies (given in Table II) of the various lamps for 500 hours life.

TABLE II.
DIFFERENCE IN RELATIVE QUALITY BETWEEN VARIOUS SIZES OF 115-VOLT TUNGSTEN FILAMENT LAMPS

Lamp	Commercial Rating initial L-P-W	Mean L-P-W for 500 hours life	Relative Quality — Hours life at 10 mean L-P-W
10 watt Vacuum	8.2	8.73	190
15 watt Vacuum	8.7	9.16	275
25 watt Vacuum	9.5	9.56	375
40 watt Vacuum	10.1	9.98	485
50 watt Vacuum	10.2	9.84	440
60 watt Vacuum	10.2	9.61	370
75 watt Gas-filled	11.8	11.9	1,600
100 watt Gas-filled	12.9	13.0	2,950
150 watt Gas-filled	14.3	14.3	5,400
200 watt Gas-filled	15.3	15.4	9,100
300 watt Gas-filled	16.5	16.6	15,200
500 watt Gas-filled	18.1	18.1	26,400
750 watt Gas-filled	19.1	18.0	25,300
1000 watt Gas-filled	20.0	18.8	35,000

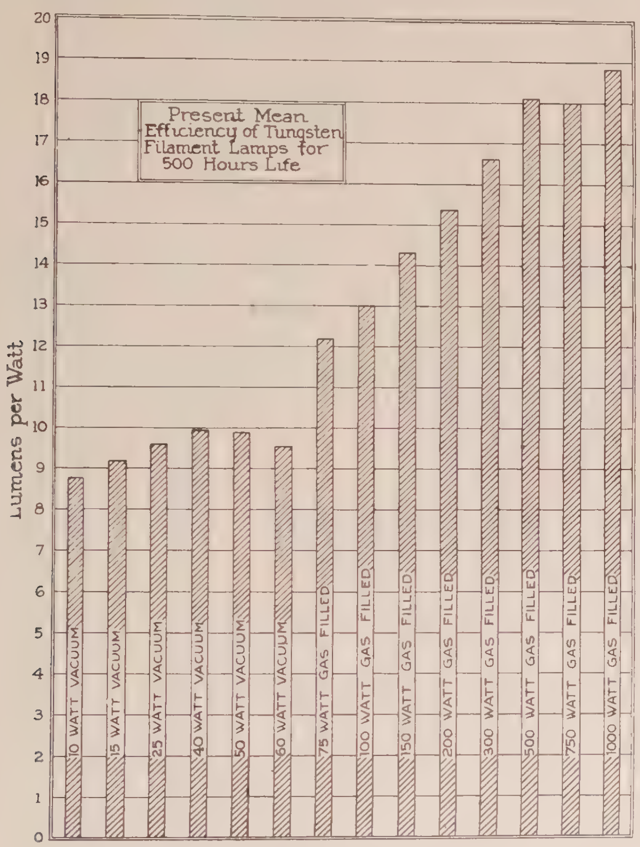

FIG. 1. PRESENT MEAN EFFICIENCIES OF TUNGSTEN FILAMENT LAMPS FOR 500 HOURS LIFE

IMPROVEMENT IN THE MOST GENERALLY USED LAMP, 1880-1923

The first commercial incandescent lamp had a carbonized paper filament. About the middle of the year 1880, carbonized bamboo was used. The term "watts" had not been adopted at that time, so the bamboo lamps were made for an efficiency of "eight lamps per horse power". The lamps were designed to give 16 candle power in a horizontal direction when new and had a rated commercial life of 600 hours to burn out. Expressing these figures in the present international candle power standard, their quality was such that it is computed that they would have given a mean efficiency of 1.12 lumens per watt during 500 hours total life. In the latter part of 1881 lamps were made at a higher efficiency for use on lighting circuits having close voltage regulation. They were made "ten lamps per horse power" rated for 600 hours life to burn out. In the

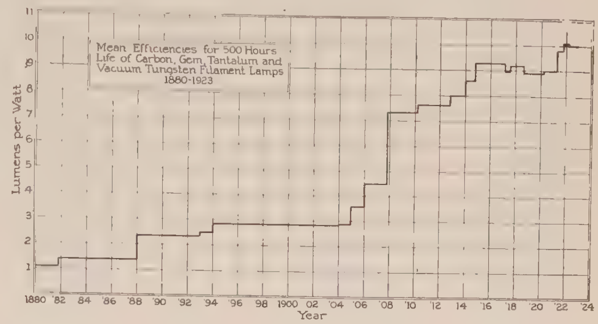

FIG. 2. IMPROVEMENT IN LAMPS, 1880-1923

years following the quality was improved by the experience gained in manufacture, the changes in the filament, etc. The most important improvements were in:

1888 Asphalted bamboo — carbon filament
1893 Treated bamboo — carbon filament
1894 Treated cellulose — carbon filament
1905 Metallized carbon filament (Gem lamp)
1906 Tantalum filament
1907 Tungsten filament
1911 Drawn tungsten wire
1912 "Getters" (chemicals used to improve the lumen maintenance)
1913 Gas-filled tungsten filament lamp.

The aggregate of these advances brought about by changes in type of filament and improvement in quality is staggering in amount. For example, the quality of the present 40-watt vacuum lamp is such that if it were made for the same mean efficiency as Edison's bamboo carbon lamp of 1880, it is estimated that the tungsten filament lamp would have a life of over one hundred and fifty thousand years. And this does not take into consideration the enormous improvement in the larger sizes of tungsten filament lamps due to Dr. Langmuir's brilliant invention of the gas-filled lamp.

Owing to such enormous differences, the improvements are therefore indicated in terms of their mean efficiencies for 500 hours life. Table III gives the mean efficiencies of the most popular size of vacuum lamp in use from 1880 to date. These data in chart form are shown in Fig. 2. To indicate the improvement made possible by Dr. Langmuir's invention, the present mean efficiencies of the 75 and 1000-watt gas-filled tungsten lamps are added at the bottom of Table III.

Due to these various improvements, the rated initial efficiencies were improved as will be seen from the figures in the third column.

TABLE III.

MEAN EFFICIENCIES FOR 500 HOURS LIFE OF CARBON, GEM, TANTALUM AND VACUUM TUNGSTEN FILAMENT LAMPS, 1880-1923

Date	Lamp	Rated Initial efficiency	Rated Hours life to burnout	Reduction factor	Mean efficiency (% initial)	Mean LPW for 500 hrs. life
1880	16 c.p. carbon (bamboo)	8 per h. p.	600	77%	65%	1.12
Oct. 1881	do do	10 per h. p.	600	77	65	1.41
1888	do (asphalted bamboo)	3.1 wphcp	600	77	70	2.30
1893	do (treated bamboo)	3.1 wphcp	600	77	75	2.45
1894	do (treated cellulose)	3.1 wphcp	600	82½	80	2.80
1900	do do	3.1 wphcp	600	82½	81	2.83
1904	do do	3.1 wphcp	600	82½	82	2.87
1905	50 watt GEM	2.5 wphcp	600	82½	82	3.56
1906	44 watt Tantalum	2.0 wphcp	700	78	85	4.46
Nov. 1907	40 watt Tungsten (pressed)	1.25 wphcp	800	78	85	7.29
Apr. 1910	do do	*1 23 wphcp	1000	78	85	7.62
1911	do (drawn)	1.23 wphcp	1000	78	85	7.62
Oct. 1912	do do	1.17 wphcp	1000	78	86	8.01
Jan. 1914	do do	1.10 wphcp	1000	78	87	8.66
Oct. 1914	do do	1.03 wphcp	1000	78	88	9.31
July 1916	do do	1.32 wpscp	1000	....	88	9.31
May 1917	do do	1.35 wpscp	1000	....	87	9.01
July 1917	do do	1.33 wpscp	1000	....	88	9.24
Aug. 1918	do do	1.36 wpscp	1000	....	87	8.93
Apr. 1920	do do	1.35 wpscp	1000	....	87	9.01
May 1921	do do	9.9 l-p-w	1000	....	89	9.77
Oct. 1921	do do	10.1 l-p-w	1000	....	90	10.10
May 1922	do do	10.1 l-p-w	1000	....	89	9.98
May 1923	do do	10.1 l-p-w	1000	....	89	9.98
May 1923	75 watt Tungsten (gas-filled)	11.8 l-p-w	1000	....	91	11.90
May 1923	1000 watt Tungsten (gas-filled)	20.0 l-p-w	1000	....	85	18.80

*The International candle in use since April 1910 is 1.6 per cent less than the standard used prior to that date.

Value of Lamp Improvements

The cost of current to the public is now very much less than in 1880. The public has increased the amount of light it has used with every reduction in rate for current and every improvement in lamps. It is difficult to determine the cost of current in the first few years, but it is assumed in the following calculations to have averaged 20c. per kw-hr., from 1880 to 1883, 15c. from 1883 to 1888 and 13c. from 1888 to 1890. Data beginning with 1890 are available on the general average rate for which current was sold so these figures are used in the calculations.

The 1880 lamp had a mean efficiency of 1.09 lumens per watt during its rated life of 600 hours, consumed about 93 watts and had a list price of one dollar. At 20c per kw-hr., about 50 lumen-hours could be obtained for one cent, covering the cost of current and lamp renewals.

The present 40-watt tungsten filament lamp has a list price of 32 cents. If it were of the same quality as the 1880 lamp it would have a mean efficiency of 1.01 lumens per watt during its rated life of 1000 hours. At the present approximate general average rate of 4½c. per kw-hr. such a lamp would produce 190 lumen-hours for one cent.

If on the other hand with no reduction in rate for current, the present 40-watt lamp, which has a mean efficiency of 9 lumens per watt during its 1000 hours rated life, would at 20c. per kw-hr., produce 432 lumen-hours for one cent.

With the combination of the reduction in rate and improvement in lamps, it is now possible at the approximate general average rate of 4½c. per kw-hr., to obtain 1700 lumen-hours for one cent. It is impossible to state exactly what part of the increase is due to lamp improvements and what part is due to reduction in cost of current, except to indicate what would have been obtainable with one factor without the other.

Table IV shows the number of lumen-hours obtained

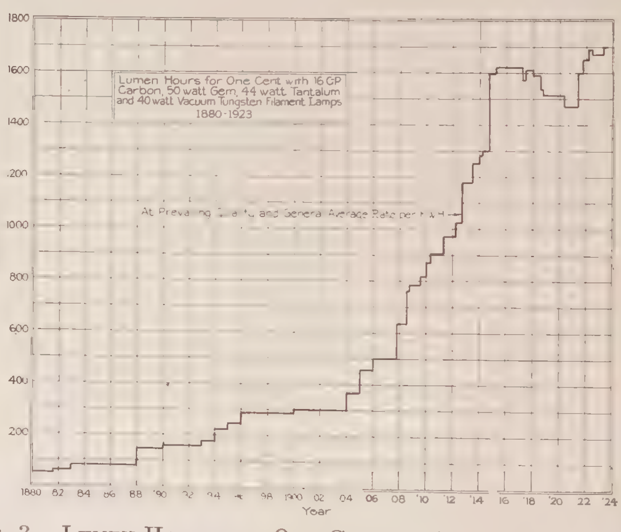

Fig. 3. Lumen-Hours for One Cent at Approximate General Average Rates for Current, 1880-1923

from time to time for one cent with the most popular size of lamp used. It is based on the prevailing lamp quality and the prevailing approximate general average rate for current. This is shown diagramatically in Fig. 3. At the bottom of Table IV is given for comparison, the number of lumen-hours now obtainable with the 75 and 1000-watt gas-filled tungsten filament lamps.

TABLE IV.
LUMEN-HOURS FOR ONE CENT, 1880-1923

Date	Rated life in hours	Mean lumens per watt during rated life	List price of lamp	Approximate general average rate per kw-hr.	Lumen hours for one cent with prevailing quality and prevailing rate per kw-hr.
16 C-P Carbon Lamp					
1880	600 (a)	1.09	$1.00	$0.20	50
Oct. 1881	600 (b)	1.37	1.00	0.20	61
1883	600 (b)	1.37	0.75	0.15	83
1888	600 (b)	2.23	0.75	0.13	143
1890	600 (c)	2.23	0.75	0.12	155
1893	600 (c)	2.38	0.75	0.11	176
1894	600 (c)	2.72	0.75	0.10	220
1895	600 (c)	2.72	0.50	0.09½	246
1896	600 (c)	2.72	0.22	0.09	283
1900	600 (c)	2.75	0.20	0.08½	300
1904	600 (c)	2.79	0.20	0.07	364
50 Watt GEM Lamp					
1905	600	3.45	0.25	0.07	440
44 Watt Tantalum Lamp					
1906	700	4.23	0.75	0.06	501
40 Watt Vacuum Tungsten Filament Lamp					
Nov. 1907	800	6.78	1.50	0.06	635
Oct. 1908	800	6.78	1.10	0.05½	759
Nov. 1908	800	6.78	1.00	0.05½	785
Sept. 1909	800	6.78	0.90	0.05½	815
Jan. 1910	800	6.78	0.80	0.05½	870
Apr. 1910	1000	6.78	0.80	0.05½	904
Apr. 1911	1000	6.78	0.70	0.05	967
Mar. 1912	1000	6.78	0.55	0.05	1020
Oct. 1912	1000	7.20	0.45	0.05	1175
July 1913	1000	7.20	0.35	0.05	1250
Jan. 1914	1000	7.77	0.35	0.05	1280
Apr. 1914	1000	7.77	0.30	0.05	1300
Oct. 1914	1000	8.38	0.30	0.05	1595
Apr. 1915	1000	8.38	0.27	0.04½	1620
May 1917	1000	8.10	0.27	0.04½	1570
July 1917	1000	8.32	0.27	0.04½	1610
Jan. 1918	1000	8.32	0.30	0.04½	1590
Aug. 1918	1000	8.04	0.30	0.04½	1535
Oct. 1918	1000	8.04	0.35	0.04½	1515
Apr. 1920	1000	8.10	0.40	0.04½	1470
May 1921	1000	8.80	0.40	0.04½	1600
Oct. 1921	1000	9.10	0.40	0.04½	1650
Apr. 1922	1000	9.10	0.35	0.04½	1690
May 1922	1000	9.00	0.35	0.04½	1670
May 1923	1000	9.00	0.32	0.04½	1700
75 Watt Gas-Filled Tungsten Filament Lamp					
May 1923	1000	11.90	0.55	0.04½	2270
1000 Watt Gas-Filled Tungsten Filament Lamp					
May 1923	1000	18.80	4.25	0.04½	3820

(a) 93.25 watts (b) 74.6 watts (c) 50 watts

The amount of light now obtainable for one cent, with the 40-watt vacuum and the 75 and 1000-watt, gas-filled tungsten filament lamps at various rates for current, is given in Table V. As in Table IV, the cost of lamps is considered as their list price. Large consumers of current obtaining low rates are usually large purchasers of lamps and hence obtain them at less than list price. Under such circumstances the amount of light obtained for a given expenditure would be somewhat greater than stated. For comparison, the amount which would have been produced by the 1880 lamp is also shown. These data are shown diagramatically in Fig. 4.

As previously mentioned, it is impossible to exactly state what part of the increase is due to lamp improvement and what part is due to the rate reduction. The improvement in lamps is indicated by the fact that the rated mean efficiency of the present 40-watt vacuum tungsten filament lamp is 8¼ times, the 75-watt gas-filled is nearly eleven times and the 1000-watt is 17¼ times that of the 1880 lamp. The rate reduction depends, of course, on the rate used.

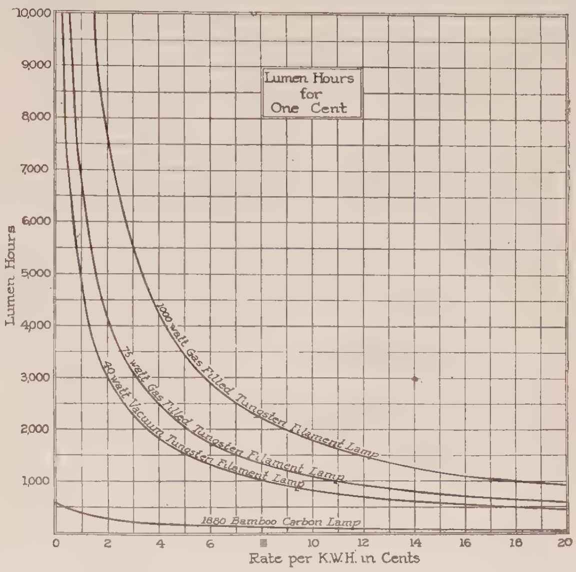

FIG. 4. LUMEN-HOURS NOW OBTAINABLE AT VARIOUS RATES FOR CURRENT

TABLE V.
LUMEN-HOURS FOR ONE CENT AT VARIOUS RATES FOR CURRENT

Rate per kw-hr.	Lumen-Hours for One Cent with 1880 carbon lamp	40-watt vacuum tungsten filament lamp	75-watt gas-filled tungsten filament lamp	1000-watt gas-filled tungsten filament lamp
1 c.	391	5000	6860	13200
2	288	3200	4150	7700
3	228	2370	3190	5500
4	188	1870	2510	4230
5	160	1550	2080	3460
6	140	1333	1760	2930
7	124	1150	1540	2530
8	111	1022	1360	2230
9	101	918	1220	2000
10	92	832	1110	1800
12	78	703	865	1510
14	69	608	755	1300
16	61	536	670	1140
18	55	480	603	1020
20	50	432	574	905

Effect of Lamp Improvements

Improvements in lamps may be utilized either to get more light for the same money or to get the same amount for less money. The American public has chosen to get more light and each advance in lamp quality has resulted in increased intensity of lighting everywhere.

It is estimated that over half a billion dollars were paid in 1922 for electricity used in the United States for electric lighting. If the present day intensity of lighting were produced by using the bamboo carbon lamp of 1880, the cost of lighting in 1922 would have been increased three and one half billion dollars. This would have required about fifty-billion additional tons of coal, about ten per cent of the total coal production in the United States, to generate the amount of light actually used.

INCANDESCENT LAMP LIFE TESTS*

Experience in testing tungsten filament lamps has shown that the lives of individual lamps vary largely from the average life, the differences between the longest and shortest often exceeding the average life. A typical survivor curve (Fig. 1) illustrates this point. A large group of Mazda lamps is represented and the nature of the curve is in no way unusual.—the proportion of early failures and long lived lamps is typical. Of course, with smaller quantitites of lamps involved, the curve would be less regular.

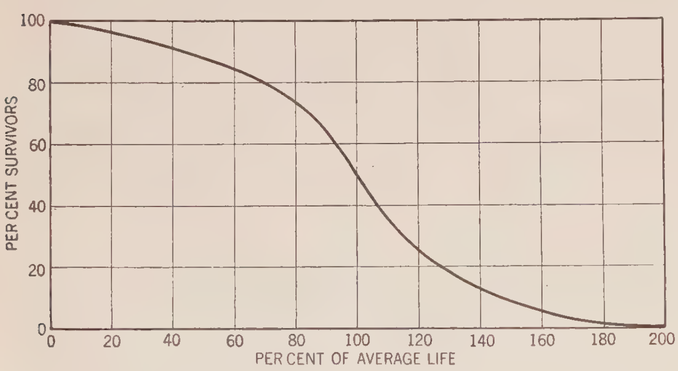

Fig. 1—Survivors Among Mazda Lamps with Respect to Hours Burned

To express the reliability of test data in tangible figures, the performance of several large groups of lamps was analyzed. The following method was employed as illustrated in one of the lots under scrutiny. The individual life values of 420 lamps of one size and type, manufactured under the same process were divided into 210 groups, each comprising two lamps, the selection being made at random. The mean life of each group of two lamps was determined and the per cent variation of each such mean life value from the average life of the entire 420 lamps (arbitrarily called "true average life") was computed.

The same batch of 420 life values were then divided into 140 groups, each comprising three lamps and similar computations were made. The process was repeated, grouping the same batch of lamps four at a time, five at a time, six at a time, etc., until there were but two groups considered, each comprising 210 lamps.

The results of the investigation are shown in Fig. 2.

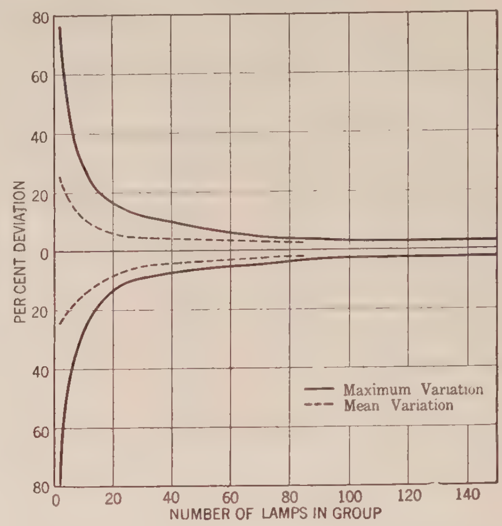

Fig. 2—Deviations of Average Life of Small Groups of Mazda Lamps from "True Average Life"

The maximum variations, positive and negative, have been plotted and in the same way the average variations encountered among the various groupings of life values have been indicated. Slight irregularities in the test data have been smoothed out for the purpose of consistency, but the curves represent faithfully the conditions existing among the lamps represented. It is evident that if we consider the "true average life" to be that of 420 lamps, then when only five lamps are selected at random, the average life of such a group may vary in the case of a random selection by as much as 45 per cent and if a number of such five lamp groups are selected at random, the average variation of the mean life values of these groups from the "true average life" is of the order of 18 per cent.

The random method of selection of the life values constituting the groups above described must be emphasized,—it is possible by selecting certain lamps, say, all of the very shortest life lamps, to pick out five lamps which might average as much as 90 per cent less than the true average life.

Facts such as have been disclosed by the foregoing analysis are given recognition in the preparation of Standard Specifications for Large Incandescent Lamps promulgated by the Bureau of Standards (Department of Commerce) in Bulletin No. 13—Ninth Edition, July 30, 1921. On page 15, tolerances are given which control the acceptance or rejection of incandescent lamps on the basis of life test results. These do not agree exactly with the curves shown in Fig. 2, because the Bureau of Standards' tolerances are influenced by the inclusion of a minimum tolerance of five per cent regardless of the number of lamps tested. However, the Standard Specification tolerances and those given in Fig. 2 are in accord in principle.

*Communicated by Electrical Testing Laboratories.

Transatlantic Radio Telephony

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Review of the Subject.—*The first transmission of the human voice across the Atlantic was accomplished by means of radio in 1915. Since that time substantial progress has been made in the art of radio telephony and in January of this year another important step was taken in the accomplishment of transoceanic voice communication. At a prearranged time telephonic messages were received in London from New York clearly and with uniform intensity over a period of about two hours.*

These recent talking tests were part of a series of experiments on transatlantic telephony which are now under way, the results of which to date are reported in the paper.

A new method of transmission radiating only a single side-band is being employed for the first time. As compared with the ordinary method of transmission, this system possesses the following important advantages:

The effectiveness of transmission is greatly increased because all of the energy radiated is effective in conveying the message; whereas in the ordinary method, most of the energy is not thus effective.

The stability of transmission is improved.

The frequency band required for transmission is reduced, thus conserving wave length space in the ether and also simplifying the transmitting antenna problem.

An important element of the high-power transmitter is the water-cooled tubes, by means of which the power of the transmitted currents is amplified to the order of 100 kilowatts or more. The direct-current power for these tubes is supplied from a 60-cycle, a-c. source through water-cooled rectifier tubes.

A highly selective and stable type of receiving circuit is employed. Methods and apparatus have been developed for measuring the strength of the electromagnetic field which is delivered to the receiving point and for measuring the interference produced by static.

The transmission tests so far have been conducted on a wave length of 5260 meters (57,000 cycles per second). The results of the measurements during the first quarter of the year on the transmission from the United States to England show large diurnal variations in the strength of the received signal and in the radio noise strength, as is to be expected, and correspondingly large diurnal variations in the ratio of the signal to noise strength and in the resulting reception of spoken words. Also, the measurements, although as yet incomplete, show a large seasonal variation.

The character of the diurnal and seasonal variations is clearly indicated in the figures. The curves present the most accurate and complete data of this kind yet obtained.

CONTENTS

ON January 15, of this year, a group of about 60 people gathered in London at a prearranged time and listened to messages spoken by officials of the American Telephone and Telegraph Company from their offices at 195 Broadway, New York City. The transmission was conducted through a period of about two hours, and during this time the words were received in London with as much clearness and uniformity as they would be received over an ordinary wire telephone circuit. During a part of the time a loud speaker was used in connection with the receiving set, instead of head receivers. The reporters present easily made a transcription of all the remarks, both with the head sets and with the loud speaker.

These tests were made possible by cooperation between the engineers of the American Telephone and Telegraph Company and the Western Electric Company, and the engineers of the Radio Corporation of America and its associated companies. The sending apparatus was installed in the station of the Radio Corporation of America, at Rocky Point, L. I., in order to make use of that company's very efficient multiple-tuned antenna. The receiving apparatus was installed in the buildings of the Western Electric Company, Ltd., at New Southgate, England.

Presented at the Annual Convention of the A. I. E. E., Swampscott, Mass., June 26-29, 1923.

This was not the first time speech had been transmitted from America to Europe. Transatlantic telephony was first accomplished in 1915, when the American Telephone and Telegraph Company transmitted from the Navy station at Arlington, Va. to the Eiffel Tower, Paris. In these earlier tests, however, speech was received in Paris only at occasional moments when transmission conditions were exceptionally favorable. The success of the present tests indicates the large amount of development which has been carried out since this first date.

The recent talking tests were carried out as part of an investigation of transatlantic radio telephony. This investigation is directed at determining (1) the effectiveness of new methods and apparatus which have been developed for telephonically modulating and transmitting the large amounts of power necessary for transoceanic operation, (2) the efficacy of improved methods for the reception of this transmission and for so selecting it as to give an extremely sharp differentiation between the range of frequencies transmitted and all the frequencies outside of this range; and (3) determining the transmission characteristics for transatlantic distances and the variation of the characteristics with the time of day and the season of the year, including the measurement of the amount of static interference.

The tests are being continued, particularly as regards the study of transmission efficiency.

Single Side-band Eliminated Carrier Method of Transmission

The method of transmission used in these experiments is what we know as the single side-band eliminated carrier method[1]. With this method,[1] the narrowest possible band of wave lengths in the ether is used, and all of the energy radiated has maximum effectiveness in transmitting the message.

As has been pointed out in other papers[2], when a carrier is modulated by telephone waves, the power given out is distributed over a frequency range, and may be conveniently considered in three parts: (1) energy at the carrier frequency itself, (2) energy distributed in a frequency band extending from the carrier upward, and having a width equal to the frequencies appearing in the telephone waves, and (3) energy in a band extending from the carrier downward, and having a similar width. The power at the carrier frequency itself makes up somewhat more than two-thirds of the total power, even when modulation is as complete as possible. Furthermore, this energy can, in itself, convey no message, as is self evident. In the present method, therefore, the carrier-frequency component is eliminated, by methods explained in detail below with the result that a large saving in power is effected. Each of the remaining frequency ranges, generally known as the upper and the lower side-band respectively, transmits power representing the complete message. It is therefore unnecessary to transmit both of these side-bands, so that in the present method one of them is eliminated. In this way the transmission of the message uses only half the frequency band required in the usual method of operation. Similarly the frequency-band accepted by the receiving set is narrowed to conform to a single side-band as compared with the usual double side-band reception, and as a result the ratio of signal to interference is improved. Certain other advantages of this method will be brought out in the further discussion.

While these advantages of the single side-band eliminated carrier method hold good for radio telephone transmission generally, they become of the utmost importance in transoceanic work, because of the necessity of conserving power in a system where the transmitting powers are large, and also because the very limited frequency range available for long distance transmission makes it imperative that each part of the range shall be utilized with the greatest of care. Before discussing the method further, the circuits and apparatus which are actually used in the tests will be described.

1. For a more complete exposition of this method see U. S. patent No. 1449382 issued to John R. Carson to whom belongs the credit for having first suggested it. Also see Carson patents Nos. 1,343,306 and 1,343,307.

2. "Carrier Current Telephony and Telegraphy" by Colpitts and Blackwell. Journal A. I. E. E., April, 1921.

"Application to Radio of Wire Transmission Engineering" by Lloyd Espenschied. *Proc. Inst. Radio Engrs.*, Oct. 1922.

"Relations of Carrier and Side-bands in Radio Transmission" by R. V. L. Hartley. *Proc. Inst. Radio Engrs.*, Feb. 1923.

The Transmitting System

The transmitting system is shown in simplified circuit form in Fig. 1. It is illustrated as grouped into three parts: The low-power modulating and amplifying stages, shown below in light lines; the high-power amplifiers, shown in heavy lines above and to the right; and the rectifier which supplies the power amplifier with high-tension direct current, shown in the upper left-hand portion of the diagram.

Referring first to the low-power portion of the system, it will be seen that the voice currents (from either a telephone line or a local microphone) are fed into a balanced type of modulator circuit and are modulated with a carrier current of a frequency of about 33,000 cycles. The operation of the balanced type of modulator in suppressing the unmodulated carrier component is explained in the Colpitts and Blackwell carrier current paper referred to above. The result of this modulating action is to produce in the output circuit of modulator No. 1, modulated current representing the two side-bands, for example, the upper one extending from 33,300 to 36,000 cycles and the lower one from 32,700 down to 30,000 cycles. These components are impressed upon a band filter circuit which selects the lower side-band to the exclusion of the upper one and of any remaining part of the carrier, with the result that only one side-band is impressed upon the input of the second modulator. This second modulator is provided with an oscillator which supplies a carrier current of 88,500 cycles. The result of modulation between the single side-band and this carrier current is to produce a pair of side-bands which are widely separated in frequency, the upper one, representing the sum of the two frequencies, extending from 118,500 to 121,200 cycles and the lower one, representing the difference between the two frequencies, extending from 58,500 down to 55,800 cycles. In this second stage of modulation there is a relatively wide separation between the two-side bands which facilitates the selection at these higher frequencies of one side-band to the exclusion of the other. Another important advantage is that it allows a range of adjustment of the transmitted frequency without changing filters. This is accomplished by varying the frequency of the oscillator in the second step. In the present case, the frequency desired for transmission is that corresponding to the lower side-band of the second modulator. The lower side-band of from 58,500 to 55,800 is therefore selected by means of the filter indicated. This filter excludes not only the other side-band but also any small residual of 90,000-cycle unmodulated carrier current which may get through the second modulator circuit if it is imperfectly balanced.

Having prepared at low power the side-band currents of desired frequency it is necessary to amplify them to the required magnitude for application to the transmitting antenna. This amplification is carried out in

three stages. The first stage increases the power to about 750 watts, and is shown in Fig. 1 together with the modulating circuits. This amplifier employs in its last stage three glass vacuum tubes rated at 250 watts each and operating at 1500 volts.

The output of the 750 watt amplifier is applied to the input of the larger-power amplifying system beginning with the 15 kw-amplifier of Fig. 1. This consists of two water-cooled tubes in parallel, operating at approximately 10,000 volts. The output of this amplifier is applied by means of a transformer to the input of the 150-kw. amplifier which consists of two units of ten water-cooled tubes each, all operating in parallel at about 10,000 volts.

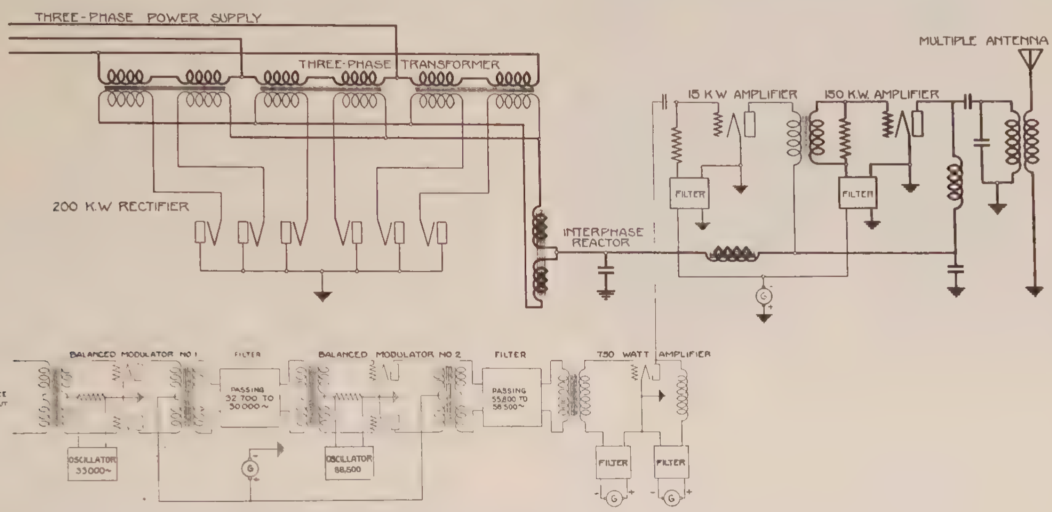

Fig. 1—Single Side-Band Eliminated Carrier Transmitter

The high-voltage, d-c. supply is furnished by a large vacuum tube rectifier unit rated at 200 kw. It employes water-cooled tubes similar to those used in the power amplifiers except that they are of the two-electrode type. The rectifier operates from a 60-cycle, three-phase supply circuit and utilizes both halves of each wave. The two sets of rectified waves are combined by means of an inter-phase reactor which serves to smooth out the resultant current and by distributing the load between tubes of adjacent phases increases the effective load capacity of the rectifier. The ripple is further reduced by the filtering retardation coil and condensers shown.

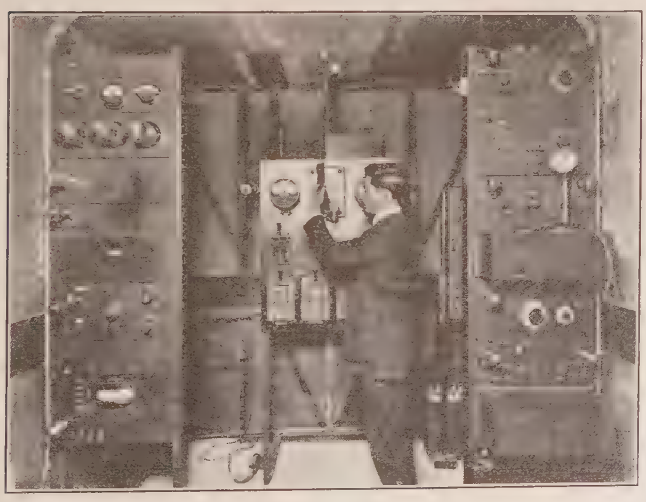

Fig. 2

Reproductions of the apparatus comprising the transmitter system as described above are given in Figs. 2, 3, 4 and 5.

Fig. 2 shows the apparatus comprising the low-power stage of the transmitting system. The right-hand rack contains the two weak-power modulating units and the two single-side-band selecting filters.

Fig. 3

The left hand rack is the 750-watt amplifier unit. The three radiation-cooled tubes of 250 watt capacity each will be seen near the top. Below are the smaller amplifying stages. The power supply board is shown in the center of the photograph.

Fig. 3 is a side view of the 15-kw. amplifier unit. The face of the panel from which the control handles protrude is on the left. Mounted in the cage behind the front panel are two water-jackets for accommodating the water-cooled tubes, also a coiled hose for increasing the electrical resistance of the water supply circuit (the water-cooled anodes of the tubes being operated above ground potential).

The final amplifier of 150 kw. capacity is shown in Fig. 4. It comprises two units each of 75 kw. Each unit contains 10 water-cooled tubes which can be seen

mounted in their water jackets. To the right of these units is located the 200-kw. rectifier unit shown in Fig. 5. The unit contains actually 12 tubes, there being two tubes for each of the six half waves. The

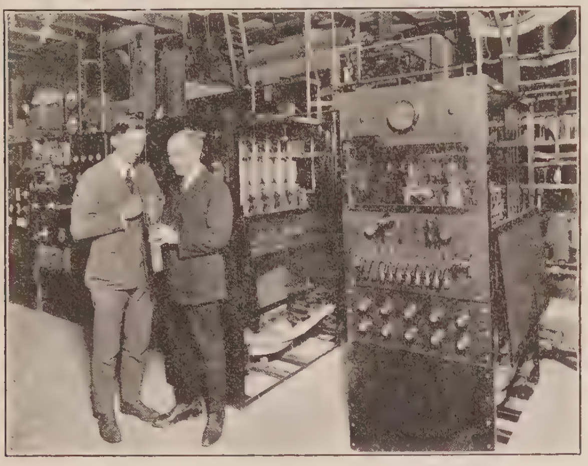

Fig. 4

pancake coils on the top of the rack are protective choke coils to guard the transformer secondary winding against steep wave fronts in case of tube failure.

From the above description it will be understood that the transmitting system is one in which the useful

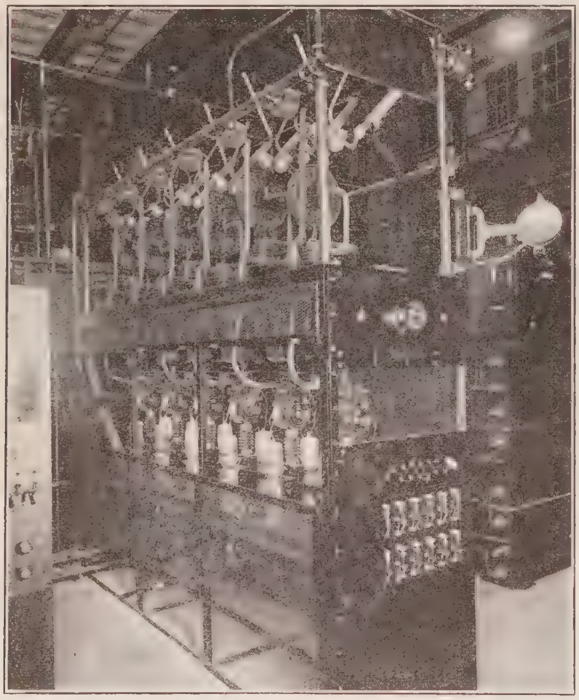

Fig. 5

side-band is first developed by modulation and filtration at low powers and then its power is built up to a large value in a succession of powerful amplifiers. It will be appreciated, therefore, that the large power amplifiers and in particular the water-cooled tubes which are their essential elements represent one of the major problems of the development.

High-Power Tubes

The development of the high-power tubes is described quite fully in another paper[3]. The present discussion is, therefore, limited to a few of the outstanding features.

In the design of high-power tubes for use in this system the main problem is to insure the ready disposal of the large amounts of heat generated at the anodes. For the conditions of use in the present type of system where the tube is employed as an amplifier, the power which must be disposed of as heat at the anode is of the same order of magnitude as the power which the tube will deliver to the antenna. In the case of the present equipment, therefore, the tube must be so designed as to operate continuously with a heat dissipation at the anode of more than 10 kw. It is obviously difficult to secure so large a dissipation in a tube enclosed with glass walls, and a tube was therefore designed in which the anode forms a part of the wall of the containing vessel and the heat generated in it is removed by circulating water. The tube used is shown in Fig. 6. The lower cylindrical portion is the anode which is drawn from a sheet of copper. The upper

Fig. 6

portion is of glass and serves both to support and insulate the grid and filament elements.

The three principal difficulties met in the construction of these tubes are the making of a vacuum-tight seal between the copper and the glass, the provision of adequate means for conducting through the glass wall the large currents necessary to heat the filament, and the obtaining of the necessary vacuum for high-power operation.

The first of these problems was solved by the development of a new metal to glass seal. In making this seal the glass and metal parts are brought into contact while hot, the temperature being high enough for the glass to wet the metal. The part of the metal in contact with the glass is made so thin that the stresses which are set up when the seal cools are not great enough to fracture the glass or to break it away from the metal at the surface of contact. Seals made in this way are sufficiently rugged to stand repeated heating and cooling from the temperature of liquid air to that of molten glass without deterioration.

A seal employing the same principle but differens in form is also used at the point where the leadt carrying the filament current pass through the glass walls of the tube. The lead is made of copper 0.064 in. in diameter and passes through the center of a copper disk, 0.010 in. thick, the joint between the lead and the

3. Bell System Technical Journal, July 1922.

disk being made vacuum-tight by the use of a high-melting-point solder. The disk is sealed to the end of a glass tube which is in turn sealed into the glass wall of the vacuum tube.

In exhausting the tubes it has been found necessary to subject all the metal parts to a preliminary heat treatment in a vacuum furnace during which the great bulk of the occluded gasses is removed. By this method the time of exhaust can be considerably reduced but the vacuum conditions to be met are so stringent that the final processes of evacuation must be carefully controlled and often occupy as much as twelve hours.

The tubes are operated at a plate voltage of 10,000 volts and are capable of delivering 10 kw. at this voltage in a suitable oscillatory circuit. For this performance an average electron current of 1.35 amperes is required. The total electron current that the filament must be capable of supplying to insure steady operation is about 6 amperes.

When the tubes are used to amplify modulated currents with large peak values such as are characteristic of telephone signals it is essential that the maximum electron current through the tube shall be several times the normal operating current and therefore to insure the necessary high quality of transmission these tubes are operated for telephone purposes with an average output of about 5 kw.

The Receiving System

In the method of transmission ordinarily employed in radio telephony by which the carrier and both side-bands are sent out from the transmitting station and received at the distant end, detection is readily accomplished merely by permitting all of these components to pass through the detector tube. The detecting action whereby the voice-frequency currents are derived, is accomplished by a remodulation of the carrier with each sideband.

With the present eliminated carrier method of transmission the side-band is unaccompanied by any carrier with which to remodulate in the receiving detector. It is necessary, therefore, to supply the detector with current of the carrier frequency obtained from a local source. Thus, in the present experiments, if a current of the original carrier frequency, 55,500 cycles, is supplied to the detector it will remodulate or "beat" with the received side-band of, say 55,800 to 58,500 cycles and a difference-frequency band of 300 to 3000 cycles, *i. e.*, the voice frequency band will result.

The arrangement actually used, however, is not quite so simple as this. It is shown schematically in Fig. 7. Reception is carried out in two steps, the received side-band being stepped down to a lower frequency before it is detected. The stepping down action is accomplished by combining in the first detector the incoming band of 55,800 to 58,500 cycles with a locally generated current of about 90,000 cycles. In the output circuit of the detector the difference-frequency band of 34,200 to 31,500 cycles is selected by a band filter and passed through amplifiers and thence to the second detector. This detector is supplied with a carrier of 34,500 cycles which, upon "beating" with the selected band, gives in the output of the detector the original voice-frequency band.

The object of thus stepping down the received frequency is to secure the combination of a high degree of selectivity with flexibility in tuning. The high selectivity is obtained by the use of a band filter. It is further improved by applying the filter after the frequency is stepped down rather than before. To illustrate this improvement assume that there is present an interfering signal at 60,000 cycles, 1500 cycles off from the edge of the received telephone band. This is a frequency difference of about 2½ per cent; but after each of these frequencies is subtracted from 90,000 cycles, the difference of 1500 cycles becomes almost 5 per cent. This enables the filter to effect a sharper discrimination against the interfering signal. Furthermore, the filter is not required to be of variable frequency as would be the case were it employed directly at the received frequency since by adjusting the frequency of the beating down oscillator the filter is in effect readily applied anywhere in a wide range of received frequencies. The receiving method, therefore, enables the filter circuit, and indeed also the inter-

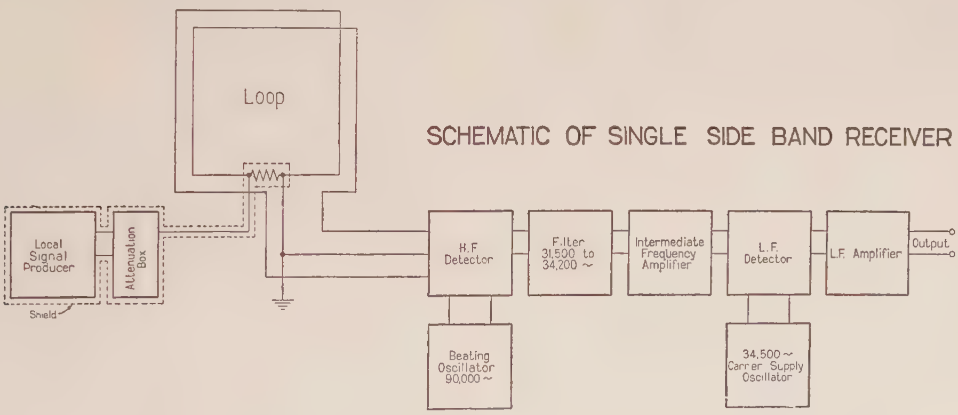

Fig. 7

mediate frequency amplifiers, to be designed for maximum efficiency at fixed frequency values without sacrificing the frequency flexibility of the receiving set.

A photograph of the receiving set used in the transatlantic measurements is reproduced in Fig. 8. The signals are received on a square loop six feet on a side and wound with 46 turns of stranded wire. The first box contains the beating oscillator and high-frequency detector, the second box the filter and amplifying apparatus for the intermediate frequency and the third box the final detector and amplifier. The shielded box at the left of the picture, which is connected to the loop by means of leads in the copper tube, is the apparatus for introducing the comparison signal of known

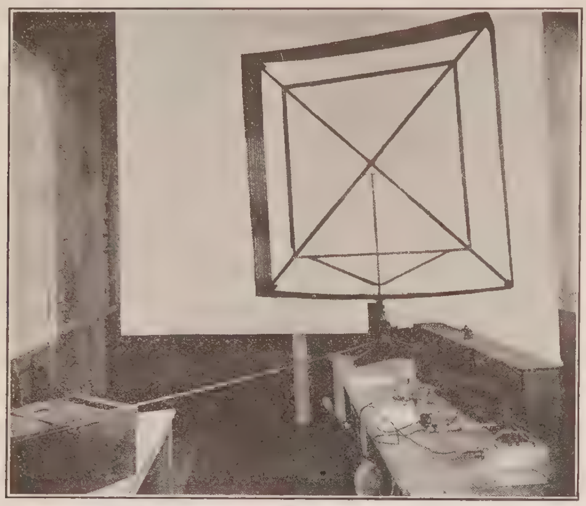

FIG. 8

strength into the loop for measuring purposes. This receiving and measuring set is described more in detail in a paper by Bown, Englund, and Friis in the *Proceedings* of the Institute of Radio Engineers for April 1923.

Although it was this very selective and reliable method of intermediate-frequency reception which was used in London, it is quite possible to receive the single-side-band transmission by means of a regular heterodyne receiving set. Even a self-regenerative set will suffice under some conditions. It is necessary, however, to adjust the frequency of the oscillator very carefully to that of the transmitting carrier frequency, otherwise serious distortion of the received speech will result. Also it is, of course, necessary that the tuning be not too sharp if ordinary tuned circuits and not filter circuits are employed. One might expect that some difficulty would be experienced in maintaining the frequency at the receiving end in sufficiently close agreement with the sending frequency. In the tests no particular difficulty was experienced, the oscillators at the two ends being so stable that only an occasional slight readjustment of the receiving oscillator was required. With the development of more stable oscillators, doubtless, the frequency with which readjustments are required, will be further reduced. If serious distortion of the received speech is to be avoided the two frequencies must be within about 50 cycles, an accuracy of 0.1 per cent at 50,000 cycles.

Transmission Advantages of the System

Since the present experiment represents the first use of the single-side-band eliminated carrier type of system some further discussion of the characteristics and advantages of the system is appropriate.

The importance of the system in conserving frequency range will be appreciated when it is realized that the total frequency range available for transatlantic telephony is distinctly limited. Just what the most suitable range is has not been accurately determined but it seems limited to below 60,000 cycles (5000 meters) because of the large attenuation suffered during the daylight hours by frequencies higher than this. On the lower end of the frequency scale, transatlantic telegraphy at present pretty well preempts frequencies below 30,000 cycles (10,000 meters). Therefore, for the present at least transatlantic telephony is limited to a range of some 30,000 cycles. Now transmission of speech requires as a minimum for good quality a single-side-band 3000 cycles wide. Allowing for variations and clearances between channels it is doubtful if the channels could be made to average closer than one every 4000 cycles for single-side-band transmission and one every 7000 cycles for the ordinary double side-band transmission. This means that even were the whole range from 30,000 to 60,000 cycles devoted to telephony to the exclusion of telegraphy, only about four channels could be obtained by the older methods and some seven by the present one.

It is a rather interesting commentary to note that a somewhat similar situation as to limitation in frequency range exists in the case of carrier-current transmission over wires. The transmission efficiency falls off with increase in frequency and limits the range of frequencies which can be economically used, in much the same way as it is limited in long distance radio transmission. It is because of this limitation in the case of wires and the value which attaches to conserving the frequency range consumed per message that single side-band transmission was first developed for wire carrier current systems. Its development in wire transmission has been of considerable aid in adapting the method to the present purpose of transatlantic operation.

The second of the outstanding characteristics of the present system resides in the large power economy which it permits. Transatlantic telephony requires hundreds of kilowatts of high-frequency power. Since it is difficult and expensive to produce this power it is important that every effort be made to increase its efficiency or effectiveness in transmitting the voice. To illustrate how the present system effects economies in power, consider the case of a carrier wave completely

modulated by a single frequency tone. In such a completely modulated wave, only 1/3 of the total power contains the message, the remaining 2/3 conveying only the carrier frequency which can as well be supplied from an oscillator of small power at the receiving station. It is obvious, therefore, that by eliminating the carrier only 1/3 as much power need be used as would be required were all the elements of the completely modulated wave transmitted. To realize the maximum advantage of this mode of operation, the system eliminates the carrier at low power and, thereby, the high-power apparatus is devoted exclusively to the amplification of the essential part of the signal.

If, after having suppressed the carrier, both side-bands were transmitted, their reception would require perfect synchronism between the carrier resupplied at the receiving end and that eliminated at the sending end, a condition which is practically impossible to meet without transmitting some form of synchronizing channel, which is, indeed, much the same as transmitting the carrier itself. If the receiving carrier is not synchronized, the two side bands will interfere with each other upon being detected. By eliminating one side-band, this interference is prevented and reception may be carried on, using a locally supplied frequency which is only approximately equal to that of the suppressed carrier. The two may differ by as much as 50 cycles before the quality of the received speech is greatly impaired. The importance to the carrier suppression method of eliminating one side-band will, therefore, be appreciated. The present system eliminates one side-band while still in the low-power stage. While it would be possible to do this selecting after they have both been raised to the full transmitting power, this would require the use of a filter of high-power carrying capacity, which would make the filter very costly and also render the system inflexible to change of wave length. The present system overcomes both of these difficulties by filtering out one side-band at low power levels and by the use of the double modulation method.

Another very important reason for the transmission of a frequency band as narrow as is possible lies in the difficulty of constructing an antenna to transmit more or less uniformly at these long waves a band of frequencies which is an appreciable fraction of the main carrier frequencies. For example, in the ordinary method of transmission an antenna which was intended to transmit a 30,000-cycle carrier and its two speech side-bands would need to be designed to transmit all the frequencies from 27,000 cycles to 33,000 cycles, a band which is equal to 20 per cent of the carrier frequency. This band is considerably wider than that given by the resonance curve of a highly efficient long wave antenna. To accommodate both side-bands would require flattening out the resonance curve either by damping, which means sacrifice in power efficiency, or by special design of the antenna, possibly throwing it into a series of interacting networks and causing it to become a rather elaborate wave filter. The importance, from the antenna standpoint, of narrowing the frequency band required to be transmitted is, therefore, evident.

It is extremely important that the received signal be affected as little as possible by changes in the transmission efficiency of the medium. The voice frequency currents produced at the receiving end, after detection, are proportional to the product of the carrier wave and the side-band. If the carrier as well as the side-band is transmitted through the medium, then a given variation in the transmission efficiency of the medium will affect both components and will change the received speech in proportion to the square of the variation, as compared to the first power if only the side-band is transmitted and the carrier is supplied locally. Thus it will be seen that the omission of the carrier from the sending end and the resupplying of it from the constant source at the receiving end gives greater stability of transmission.

Without discussing the system in further detail the advantages of it may be summarized as follows:

1. It conserves the frequency (wave length) band required for radio telephony, which is particularly important at long wave lengths.

2. It conserves power, in that all of the power transmitted is useful signal-producing power. This is particularly important also in long distance transmission which requires the use of large powers.

3. The fact that only a single band of frequencies is transmitted simplifies the antenna problem at long wave lengths, where the resonance band becomes too narrow to transmit both side-bands.

4. As compared with a system which eliminates the carrier but transmits both side-bands the simple side-band system has the important advantage of not requiring an extreme accuracy of frequency in the carrier which is resupplied at the receiver. Were both side-bands transmitted very perfect synchronism would be required for good quality.

5. It improves the transmission stability of the radio circuit since variations in the ether attenuation affect only one (the side-band) of the two components effective in carrying out the detecting action in the receiver.

6. The receiving part of the overall system has two advantages:

a. It need accept only half of the frequency band which would be required in double side band transmission, thereby accepting only half of the "static" interfering energy.

b. By stepping down the frequency of the received currents and filtering and amplifying at the low-frequency stage a very sharp cutoff is obtained for frequencies outside of the desired band and a very stable and easily maintained amplifying system is obtained.

Study of Transatlantic Transmission

We come now to a consideration of the second major part of the investigation, namely, that having to do with the transmission of the waves across the Atlantic. It will be evident, from what has been said earlier, that the transmission question is essentially one of how best to deliver, through the variable conditions of the ether to the receiving station, speech-carrying waves sufficiently free from interference to be readily interpretable in the receiving telephone. The transmission efficiency of the medium varies with time of day and year, and is different for different wave lengths. The interference conditions are also influenced by these same factors.

Now we can study this transmission medium in much the same way we would a physical telephone circuit, by putting into it, at the sending end, electromagnetic waves of a known amount of power and measuring the power delivered at the receiving end. The interference at the receiving station likewise may be measured and the ratio of the strength of the signal waves to the interfering waves may be taken as a measure of freedom from interference; this in turn being directly related to the readiness with which the messages are understood. Accordingly, there has been included as an integral part of the investigation of transatlantic radio telephony, the development of suitable methods and apparatus for measuring the strength of the signal waves and of the interfering waves, as they arrive at the receiving station. The apparatus[4] employed in measuring the field strength of the received signals has been outlined above under Receiving System and need not be gone into further. However, a word of explanation about the method which is employed in making the measurement may be helpful. It will be recalled that the specially designed receiving set is provided with a local source of high frequency from which can be originated signals of predetermined strength. A measurement of the field strength of a signal received from the distant transmitter is made by listening first to the distant signal and then to the locally produced signal, shifting back and forth between these signals and adjusting the strength of the local signal until the two are substantially of the same strength. Then, knowing the power delivered by the local source, the power received from the distant station is likewise known. The relation between the power in the input of the radio receiving circuit to the field strength required to deliver that power is known through the geometry of the receiving antenna (in this case a loop) and, therefore, the measured power of the signal can be translated directly into the field strength of the received waves.

The measurement tone signal is transmitted from the Rocky Point sending station by substituting for the microphone telephone transmitter a source of weak alternating current of about 1/100 watt at a frequency of approximately 1500 cycles. This tone modulates the radio telephone transmitter in the same way that voice currents would and is radiated from the antenna as a single-frequency wave of 5260 meters (57,000 cycles per second). It, therefore, constitutes a means of sending out a single-frequency continuous wave for measurement purposes. At the receiving end this continuous wave is demodulated to the same tone frequency which it originally had.

For measuring the strength of the received noise, *i. e.*, the radio frequency currents arising from static or other station interference, the method is quite similar. In this case, however, the noise received is so different from that which can be set up artificially in any simple manner that no attempt is made to compare it directly with a local noise standard. Instead the volume of the interfering noise is expressed in terms of its effect in interfering with the audibility of a local tone signal by measuring the local signal which can just be definitely discerned through it. This is a threshold type of measurement which is necessarily difficult to carry out with accuracy. In order to increase the sharpness of definition of the local signal and to make it correspond more closely to speech reception the signal tone is subjected to a continuous frequency fluctuation. The comparison signal has therefore a warbling tone which occupies a frequency band not unlike that of the voice. This method of measuring the interference is discussed in more detail also in the measurement paper referred to above.

Procedure in Making Transmission Measurements. The three quantities which are included in the transmission measurements, namely, the signal strength, the noise strength, and the percentage of words received correctly, are observed one after another in what might be termed a unit test period. Although the duration of this test period and the order of making the measurements has been changed somewhat during the course of the experiments, the following program is representative of the conditions under which the data presented below were taken.

A 25-minute test period divided as follows:

5 minutes of tone telegraph identification signals (for receiving adjustment purposes).

10 minutes of disconnected spoken words.

10 minutes of a succession of five-second tone dashes separated by five-second intervals, (for measurement of the received field strength, the intervals between the dashes being used for throwing on the local receiving source and adjusting its strength to equal that of the received signals by alternately listening to one and then the other).

Immediately following this test period the London observers measured the noise level.

This unit test period was repeated every hour over a period which varied from several hours to as long as two days' duration. Most of the test periods ran for about 28 hours, starting about eleven o'clock Sunday morning

4. It is described in detail in the paper entitled, "Radio Transmission Measurements" by Bown, Englund, and Friis, *Proc. Institute of Radio Engrs.*, April 1923.

and continuing until about three o'clock Monday morning, London time. During this time the telegraph load through the Rocky Point station of the Radio Corporation was sufficiently light to enable one of the two antennas to be devoted to these experiments. The

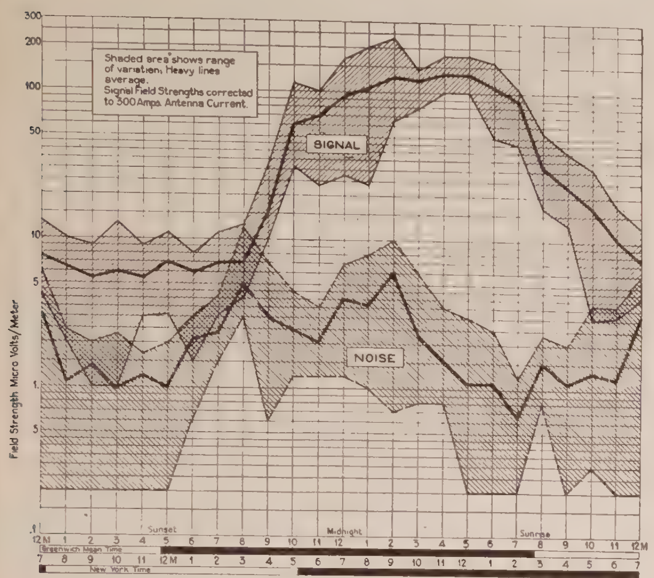

FIG. 9—TRANSATLANTIC RADIO TRANSMISSION MEASUREMENTS. DIURNAL SIGNAL AND NOISE VARIATION, JANUARY 1,—FEBRUARY 23, 1923.

measurements were started January 1, 1923 and are still in progress.

At the present time (April) the results for the first three months of the tests are available. These results are not yet sufficiently complete nor do they cover a

TRANSATLANTIC RADIO TRANSMISSION MEASUREMENTS
DIURNAL SIGNAL & NOISE VARIATION
Feb25–Apr 9, 1923.

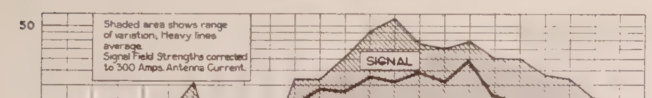

FIG. 10

sufficient number of variables in terms of time, wave length, etc., to enable any very definite conclusions to be drawn from them. They do illustrate, however, the usefulness of the methods employed, and even in their incomplete state show some factors of considerable interest.

The results of the measurements of received signal strength and received noise are given in Figs. 9 and 10. The data have been divided and plotted in these two sets of curves because the transmission conditions across the North Atlantic appeared to suffer a rather rapid change about February 23rd. Fig. 9 therefore covers the winter period from January 1 (when the test started) to February 23; and Fig. 10 covers the next period from February 25 to April 9.

The curves are plotted between time of day as abscissas and field strength in microvolts per meter as ordinates. The time during which darkness prevailed at Rocky Point and at London is indicated by the block-fills on the time scales. The overlap of these block-fills indicates the time during which darkness extended over the entire transatlantic path. For Fig. 9 the darkness-belt is as of February 1 and for Fig. 10 as of March 21. The curves show the mean of the results and also the boundaries of the maximum and minimum values observed.

Received Signal Strength. The outstanding factors to be noted concerning the signal strength curves are:

1. The diurnal variations are plainly in evidence. During the first test period covered by Fig. 9, for example, the field strength varied in the ratio of the order of 15 to 1 between day and night conditions, running about 100 microvolts per meter during the night and averaging about 6 microvolts per meter during the day. The diurnal variation is also to be seen in Fig. 10 although the variations between night and day transmission are less marked.

The measured daylight values lend support to the Austin-Cohen absorption coefficient. The average of the observed daylight values for the period of these tests is between 7 and 8 microvolts per meter, while the calculated value is 9.5. Concerning the high field strengths obtaining at night, it should be noted that the maximum observed value of 237 microvolts per meter does not exceed the value of some 340 microvolts which it is estimated should obtain at London were no absorption present in the intervening medium, *i. e.*, were the waves attenuated in accordance with the simple inverse-with-distance law. While no definite conclusions can yet be drawn from these results as to the cause of the diurnal variations, this indication that the upper limit of the variation is the no-absorption condition suggests that the diurnal fluctuations are controlled by the absorption conditions of the medium rather than by reflection or refraction effects.

2. An indication of the seasonal variation which apparently occurs in developing from winter to early spring is found in a comparison of the signal strength curves of Fig. 9 and 10. On the whole the signal strength received in the second test period is considerably less than that received for the first period. This drop in the average of the 24 hours is caused by a large decrease in the night-time transmission efficiency. The daylight transmission does not change much, but

what little change there is lies in the direction of an increase as the season advances.

3. A decrease in the transmission efficiency is observed between the time of sundown in London and sundown in New York, that is, during the period when the sunset condition intervenes in the transmission path. This dip is particularly noticeable in the signal strength curve of Fig. 10. It is not noticeable in Fig. 9, except for the fact that the rise in signal strength corresponding to night conditions in London is delayed until the major part of the transmission path is in darkness.

Strength of Received Noise. The variation in the strength of received noise is shown by the noise curves of Figs. 9 and 10.

1. The diurnal variation of that portion of the noise which is due to atmospheric or "static" disturbances is somewhat obscured by the presence of artificial noise, *i. e.*, noise caused by interference from other stations. The rise in the noise curve at 12 noon is known to be due to artificial interference. In general, however, the large noise values shown to prevail throughout the night in London between about 6 p. m. and 4 a. m. are known to be due to atmospherics. This diurnal variation shows up quite prominently in both figures.

The maximum noise is reached at 2 a. m. London time. Up to this time the night belt extends over London and a sector of the earth considerably to the east and including Europe, Africa and Asia. The noise begins to drop off shortly thereafter and reaches its minimum at sunrise in London. This could be accounted for on the assumption that the major source of the noise lies considerably to the east of London and that transmission of the stray electric waves to London is gradually diminished in efficiency as daylight overtakes the path of transmission.

2. The seasonal variation, as shown by a comparison of the noise curve of Fig. 9 with that of Fig. 10, is not so great as is the case with the transmission efficiency of the signal. However, the noise level is noticeably higher during the second period of the tests,[5] as shown by the average curve of Fig. 10, particularly during the night when the maximum noise obtains.

This indicates that the noise is largely of continental origin lying to the east or south east of London which is in agreement with rough observations made by means of a loop and suggests that the employment of directional antennas would be of considerable advantage. It is expected to include such antennas in the further measurement work.

In connection with these noise curves it should be noted that what they represent is in reality the strength of a local warbling tone-signal, expressed in terms of equivalent field strength in microvolts, which is just definitely audible through the noise. The actual value of the noise currents, were they measured by an integrating device such as a thermocouple, for example, would be a number of times larger than indicated.

Ratio of Signal to Noise Strength; Words Received. The noise curve of Fig. 9 and that of Fig. 10 can, therefore, be read as "The strength of the signal tone which can just be heard through the noise." It can, therefore, be directly compared with the signal curve itself and the difference between the two curves is a measure of the level of the actual signal strength above that which would just permit of the signals being heard. Actually, the difference between the two curves, as shown in the figures, is proportional to the *ratio* of the signal to the noise strength, because the curves are plotted to a logarithmic scale.

This signal to noise ratio is plotted in Fig. 11 for the test period which corresponds to Fig. 9, and Fig. 12 for the test period which corresponds to Fig. 10. These ratio curves are derived by going back to the original data and taking the ratio for each unit measurement period and spotting it upon the chart as shown by the black points. An average is taken of the points for each hour of the 24-hour period as shown by the circle points. The dash line curves of Figs. 11 and 12, therefore, trace the average diurnal variation of signal to noise ratio.

These curves show:

1. That the signal-to-noise ratio reaches its minimum during the time when the sunset period intervenes between London and New York.

2. During the night in London the ratio increases more or less continuously and reaches a maximum around the time of sunrise in London.

3. During the course of the daylight period in London the ratio starts out high and drops rather rapidly during the forenoon and assumes a more or less constant intermediate value during the afternoon until sundown. It is during this afternoon period in London that the business hours of the day in London and New York coincide, so that this is the most important period from a telephone communication standpoint.

The drop in the very low ratios obtaining in London in the early evening is due to the fact that an increase in noise occurring at this time is accompanied by a decrease in transmission efficiency from America. This may readily be seen by referring to Fig. 10. The noise increases as the night belt, proceeding westward, envelopes England and improves the transmission of atmospherics, which arise possibly in continental Europe, Asia and Africa. As the shadow wall, proceeding westward, intervenes between England and America, the transmission efficiency of the desired signals from America drops and it is not until the night belt extends as far west as America that the transmission efficiency improves sufficiently to overcome the disadvantage in London of the large noise values which night there had brought on. Conversely, the high signal to noise ratio, obtaining at about sunrise in London, appears to be due to the fact that as the termi-

5. The results obtained more recently than time has permitted to include in the curves show a continual rise in the level of the noise during April.

nation of the night belt, moving westward, intervenes between England and the source of atmospherics to the east, the noise level drops rapidly and has reached low values by the time sunrise arrives in London. At this

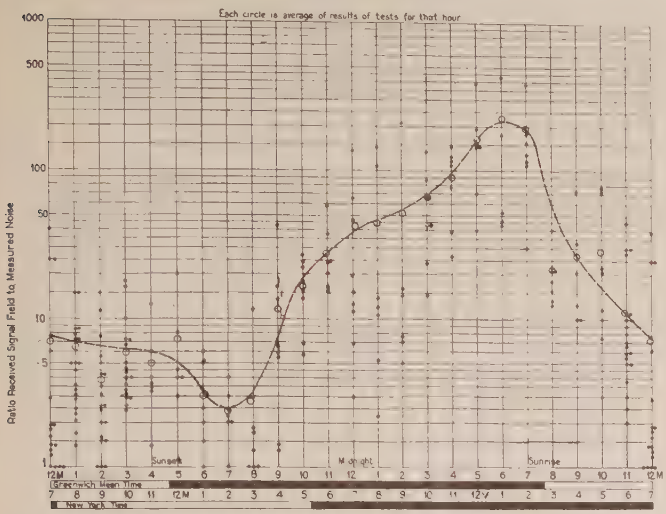

Fig. 11—Transatlantic Radio Transmission Measurements. Diurnal Variations of Signal to Noise Ratio, January 1—February 23, 1923.

time, however, darkness still extends to the west and the transmission efficiency from America is at its maximum. It is, therefore, due to this interplay between these two factors, signal strength and noise strength,

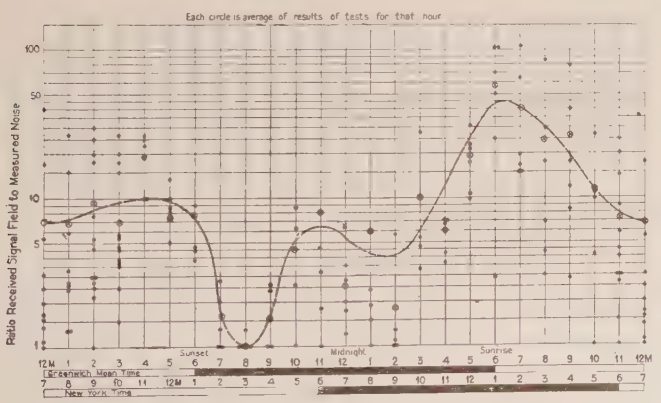

Fig. 12—Transatlantic Radio Transmission Measurements. Diurnal Variations of Signal to Noise Ratio. February 23—April 9, 1923.

controlled very largely by the transition periods between day and night, that the signal to static ratio varies diurnally in the manner pictured in Figs. 11 and 12.

Concerning seasonal variation, shown by a comparison of Figs. 11 and 12, the following can be said: The diminution in signal-to-noise ratio in the second test period as compared with the first is caused by the fact that the signal strength has decreased and at the same time the noise has somewhat increased. There is just one other point and that concerns the dip in the ratio occurring at night in London between 12 midnight and 3 a. m. This dip is due to an increase in the noise which occurs around 2 a. m. (A further reduction during this time, and one which extends the time of minimum ratio from sundown on through the night until 2 a. m. is shown by the April measurements which time has not permitted including in the curves).

During each test period lists of disconnected words were spoken over the systems. As an approximate and easily applied method of indicating the talking effi-

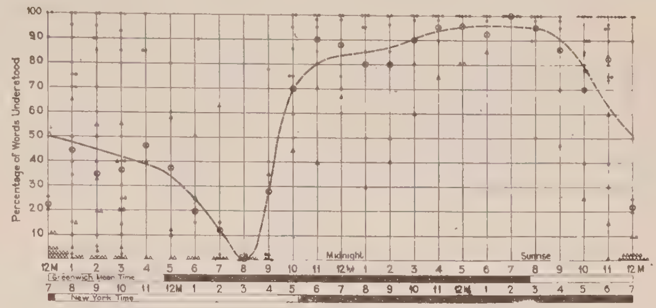

Fig. 13—Transatlantic Radio Transmission Measurements. Diurnal Variation of Words Understood, January 1—February 23, 1923.

Each circle is average of all tests for that hour including triangular points. The latter are known to be cases in which low percentage is due to unnatural causes.

ciency of the circuit, note was made of the percentage of the words which were correctly received.

The curves of Figs. 13 and 14 show the manner in which the percentage of the words which were correctly received varies through the 24 hours. Each point corresponds to the percentage of words correctly received during one unit test period. In many of these tests the interference was noted to be caused by radio telegraph stations, and the data in which the inter-

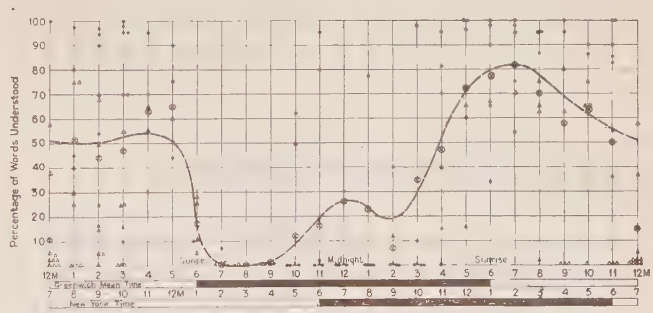

Fig. 14—Transatlantic Radio Transmission Measurements. Diurnal Variation of Words Understood, February 25—April 9, 1923.

Each circle is average of all tests for that hour including triangular points. The latter are known to be cases in which low percentage is due to unnatural causes.

ference is of this character, in so far as identified, are indicated by the triangular dots. It will be seen that most of the poor receptions were due to this cause. Especially is this true of tests at 12 noon at which

time severe interference from sources local in London was experienced. The circle points are the average of results for each hour's tests. The dash line curve is a smoothing out curve of these points.

It is interesting to note that these curves of actual word count conform very well in general shape with those of Figs. 11 and 12 which also really measure receptiveness although in a less direct manner. Reception is best during the late night and early morning, drops off during the day, reaching a minimum during the evening. Furthermore, the night reception is shown to be considerably better for the January-February period than for the February-March period. The curve of Fig. 14 corresponds quite closely with that of Fig. 12. The curve of Fig. 13 does not show as much of a peak as does that of Fig. 11 which is, of course, due to the fact that above a certain ratio the percentage of words understood is high and cannot rise above 100 per cent.

Conclusion

As has been indicated this is a report of work which is still in progress. To date:

A new type of radio telephone system affording important advantages for transatlantic telephony has been developed and put into successful experimental operation across the Atlantic.

Sustained one-way telephonic transmission has been obtained across the Atlantic for the first time by means of this system.

The advantages of this system which had been anticipated, particularly, in respect to economies of power and wave lengths, have been realized. Furthermore, it has been demonstrated that the high-power water-cooled vacuum tubes which have seen their first prolonged operation in this installation are admirably adapted for use in high-power radio installations and particularly for use as high-power amplifiers, in the type of system we have described. Also, the method of reception has proved itself to be eminently satisfactory for use with the single side-band type of transmission and to possess important advantages for radio telephony in respect to selectivity and amplification.

Methods have been developed for measuring the strength of the received signals and the strength of the received interfering noise and these methods have been successfully applied in the initiation of a study of the variations to which transatlantic transmission is subject.

The results of the transmission measurements show that, at 5000 meters, the diurnal variations are large, as was to be expected, and give evidences of a large seasonal variation which was, indeed, also to be expected. The results indicate that it will probably be desirable to use a wave length longer than 5000 meters. The measurements are now being made to include the longer wave lengths.

USE OF KILOCYCLES IN RADIO

The Second National Radio Conference, which met last March, introduced a method of designating radio waves which may not be familiar to all those interested in radio work. This is the use of frequency in kilocycles (abbreviated kc) instead of wave length in meters. This practise has many advantages, and it is believed that it will eventually replace the other method of designation.

The separation of the frequencies of transmitting stations to prevent interference is an important matter, and the necessary separation as expressed in frequency is the same no matter what the frequencies of the two stations may be, while it is variable and quite misleading when expressed in meters. Thus, the frequency band existing between 150 to 200 meters (2000 to 1500 kc) is enormously wider than the band from 1000 to 1050 meters (300 to 286 kc). While it is possible to carry on 50 simultaneous radio telephone communications between 150 and 200 meters, only one could be carried on between 1000 and 1050 meters.

It is very simple to obtain the approximate relation between kilocycles and meters. For example, knowing the wave length in meters, divide 300,000 by the number of meters to obtain the frequency in kilocycles, or knowing the wave length in kilocycles, divide 300,000 by the number of kilocycles which will give the wave length in meters. A table which may be used for rapid and accurate conversion can be obtained from the radio laboratory of the Bureau of Standards.

REDUCING THE GUESSWORK IN TUNING

The chief of the radio section of the Bureau of Standards has published in the July issue of Radio Broadcast an article "Reducing the Guesswork in Tuning" which gives a general statement of the methods employed in establishing frequency standards and making them available to the public.

The Second National Radio Conference recommended that radio broadcasting and other transmitting stations operate accurately on the frequencies to which they are assigned. The attainment of the necessary accuracy is made possible by improvements which have been carried out during recent months at the Bureau of Standards in its frequency measurements. Standards of frequency can now be furnished which permit the setting of transmitting stations on the correct number of kilocycles. The fundamental frequency basis has been established by four independent methods of primary standardization. The frequency standards are furnished through the transmission of the standard frequency signals which have been described in the last two numbers of the *Bulletin*, in the testing of wave meters, and in the measurement by the Bureau of frequency of various transmitting stations, the frequencies of which are known to be kept constant.

A Precise Method of Calculation of Skin Effect in Isolated Tubes

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A precise method of calculation is describ d for determining the skin effect in isolated tubular conductors. This may be used where more accurate results are desired than are given by the curves and approximate methods of calculation previously published by the writer.

The present calculation requires the use of certain numerical values of Bessel functions, a table for which is given. Asymptotic series for calculating them are given, which are complete with their general terms.

An example is worked out, and the result checked up with the published curves.

APPROXIMATE methods for calculating skin effect in isolated tubular conductors, and sets of curves giving numerical values, have been published by the writer.[1,2]. In the present paper, a method is presented for obtaining precise calculated values of the skin effect in isolated round tubular conductors at any frequency.

Some tables of Bessel functions from the reports of the British Association for the Advancement of Science, which are useful in this and other calculations, are printed herewith. (See Table I.)

Series are presented for calculating the values of the functions for large values of the argument. These series have the valuable feature that they are complete with their general terms.

Let i be the sinusoidal current density in absamperes per sq. cm. at a radius of the tubular conductor, Fig. 1, equal to y cm. Then, as derived in the writer's paper of 1918, reference 1, eq. (**29**),

$$\frac{d^2 i}{d y^2} + \frac{1}{y}\frac{d i}{d y} - j m^2 i = 0 \qquad (1)$$

where $$m^2 = \frac{4 \pi \mu \omega}{\rho}$$

μ = permeability of the material of the tube (assumed = 1 for copper.)

$\omega = 2 \pi f$

f = frequency in cycles per second,

ρ = specific resistivity of the material of the tube in absolute units,

$j = \sqrt{-1}$

Equation (**1**) is a well-known differential equation for alternating current in a round conductor.[3,4]

1. "Skin Effect in Tubular and Flat Conductors," by H. B. Dwight, TRANSACTIONS A. I. E. E., 1918, page 1379.

2. "Skin Effect and Proximity Effect in Tubular Conductors," by H. B. Dwight, JOURNAL of the A. I. E. E., March, 1922, page 203.

3. See "The Effective Resistance and Inductance of a Concentric Main," by Dr. A. Russell, *Philosophical Magazine*, Vol. 17, 1909, page 524.

4. See "Theory of Alternating Currents," by Dr. A. Russell, Second Edition, Vol. 1, Chap. 7, pages 205-234.

The solution of this differential equation is given in Bessel functions as follows:

$$i = (A + j B)\,(\text{ber}\, m y + j\, \text{bei}\, m y) + (C + j D)\,(\text{ker}\, m y + j\, \text{kei}\, m y) \qquad (2)$$

where A, B, C and D are undetermined constants.

The quantity $(\text{ber}\, m y + j\, \text{bei}\, m y)$ is a Bessel function of the first kind, order zero and argument $(m y \sqrt{-j})$. The quantity $(\text{ker}\, m y + j\, \text{kei}\, m y)$ is a Bessel function of the second kind, order zero and argument $(m y \sqrt{-j})$. Their values can be found from Table I of this paper or calculated from series as described later.

Since the tube is isolated, there is no proximity effect and Bessel functions of higher orders are not involved.[5]

Now when $y = q$, $\dfrac{d i}{d y} = 0$, from equation (**26**), reference 1.

Therefore,
$$(A + j B)\,(\text{ber}'\, m q + j\, \text{bei}'\, m q) + (C + j D)\,(\text{ker}'\, m q + j\, \text{kei}'\, m q) = 0 \qquad (3)$$

since $\text{ber}'\, m y = \dfrac{d}{d\, m y}\, \text{ber}\, m y$, etc.

$$\text{Thus,}\quad \frac{C + j D}{A + j B} = - \frac{(\text{ber}'\, m q + j\, \text{bei}'\, m q)}{(\text{ker}'\, m q + j\, \text{kei}'\, m q)} \qquad (4)$$

This can be found as a numerical complex quantity by taking the values of $\text{ber}'\, m q$, etc., from Table I.

The total current in the tube is

$$I = \int_q^r 2 \pi y i\, d y \qquad (5)$$

for which integrals given in reference 1, following equation (**34**), are required.

Then
$$I = \frac{2\pi}{m} \Big[(A + j B)\, y\, (\text{bei}'\, m y - j\, \text{ber}'\, m y) + (C + j D)\, y\, (\text{kei}'\, m y - j\, \text{ker}'\, m y) \Big]_{y=q}^{y=r}$$

5. See equations (**8**) and (**19**), "Wave Propagation over Parallel Wires: The Proximity Effect," by J. R. Carson, The *Philosophical Magazine*, April, 1921, page 607.

The quantity in the brackets is equal to 0 when $y = q$, as is seen by dividing equation (3) by j.

Therefore, $I = \dfrac{2\pi r}{m} [\,(A + j\,B)\,(\text{bei}'\,m\,r$

$- j\,\text{ber}'\,m\,r) + (C + j\,D)\,(\text{kei}'\,m\,r$

$- j\,\text{ker}'\,m\,r)\,]$ **(6)**

Let Z' be the effective impedance per centimeter of the tube at a certain frequency due to its effective a-c. resistance R' and its inductance caused by flux inside the metal. Since this flux does not cause any drop where $y = r$, we have

$$e = I\,Z' = \rho\, i_{(r)}$$
$$= \rho\,[\,(A + j\,B)\,(\text{ber}\,m\,r + j\,\text{bei}\,m\,r) + (C + j\,D)\,(\text{ker}\,m\,r + j\,\text{kei}\,m\,r)] \quad (7)$$

The resistance of the tube to direct current is

$$R = \frac{\rho}{\pi\,(r^2 - q^2)} \quad (8)$$

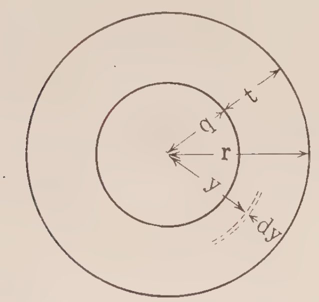

Fig. 1—Section of Tubular Conductor

Then $I\,R = \dfrac{2\,r\,\rho}{m\,(r^2 - q^2)} [\,(A + j\,B)\,(\text{bei}'\,m\,r$

$- j\,\text{ber}'\,m\,r) + (C + j\,D)\,(\text{kei}'\,m\,r$

$- j\,\text{ker}'\,m\,r)\,]$ **(9)**

From (7) and (9),

$$Z'/R = \frac{j\,m\,r}{2}\;\frac{(r^2 - q^2)}{r^2}$$

$$\frac{\left[(\text{ber}\,mr + j\,\text{bei}\,m\,r) + \dfrac{(C + j\,D)}{(A + j\,B)}\,(\text{ker}\,m\,r + j\,\text{kei}\,m\,r)\right]}{\left[(\text{ber}'\,mr + j\,\text{bei}'\,mr) + \dfrac{(C + j\,D)}{(A + j\,B)}\,(\text{ker}'\,mr + j\,\text{kei}'\,mr)\right]} \quad (10)$$

Dimensions are in centimeters.

The numerical value of $\dfrac{C + j\,D}{A + j\,B}$ is determined from equation (4) and Table I, and numerical values of ber $m\,r$, etc., can be taken from Table I. This gives the ratio Z'/R as a numerical complex quantity. The real part is equal to R'/R, the skin effect resistance ratio of the tube. The unreal part gives the change in inductance of the tube due to frequency.

For large values of $m\,r$, the following asymptotic formula for R'/R, based on series (16) to (19), may be used for approximate results. See Reference 1, page 1403.

$$R'/R = \frac{m\,t\,(q + r)}{2\,r\,\sqrt{2}}\left(1 + \frac{1}{m\,r\,\sqrt{2}} + \frac{3}{8\,m^2\,r^2} + \frac{0}{m^3\,r^3} + \ldots\right) \quad (11)$$

where t is the thickness of the tube.

The tables of ber x, bei x and ber$'\,x$ and the table of bei$'\,x$ from $x = 0.1$ to $x = 6.4$ were published by Professor A. G. Webster in the *Report of the British Association for the Advancement of Science*, 1912, page 56. The corrected values of bei$'\,x$ from $x = 6.5$ to $x = 10$ were presented in the same publication in 1916, and the tables of ker x, kei x, ker$'\,x$ and kei$'\,x$, in 1915, by H. G. Savidge. The writer has corrected the published value of bei 8.9 which contained a typographical error.

For small values of x the values in the table may be calculated by power series in x. See *Report of the British Association for the Advancement of Science*, 1916, page 108. Series for the derivatives, ber$'\,x$, etc., can be easily written down by differentiating the terms of the series for ber x, etc.

For large values of x we have

$$J_n\,(x\,j\,\sqrt{j}) = I_n\,(x\,\sqrt{j}) = \frac{e^{x\,\sqrt{j}}}{\sqrt{2\,\pi\,x\,\sqrt{j}}}\Big[1 - \frac{(4\,n^2 - 1^2)}{8\,x\,\sqrt{j}\,|\underline{1}} + \frac{(4\,n^2 - 1^2)\,(4\,n^2 - 3^2)}{(x\,\sqrt{j})^2\,|\underline{2}} - \ldots$$
$$+ (-1)^s\,\frac{(4\,n^2 - 1^2)\,(4\,n^2 - 3^2)\ldots\{\,4\,n^2 - (2\,s - 1)^2\,\}}{(8\,x\,\sqrt{j})^s\,|\underline{s}} + \ldots\Big] \quad (12)$$

This is a Bessel function of order n.

Now
$$\sqrt{j} = e^{j\frac{\pi}{4}} = \cos \pi/4 + j \sin \pi/4 = 1/\sqrt{2} + j/\sqrt{2} \quad (13)$$

and
$$\sqrt[4]{j} = e^{j\frac{\pi}{8}} = \cos \pi/8 + j \sin \pi/8 \quad (14)$$

Put $e^{j\frac{x}{\sqrt{2}} - j\frac{\pi}{8}} = \cos\,(x/\sqrt{2} - \pi/8) + j \sin\,(x/\sqrt{2} - \pi/8)$

Then
$$I_n\,(x\,\sqrt{j}) = \frac{e^{\frac{x}{\sqrt{2}}}}{\sqrt{2\,\pi\,x}}\Big[\cos\,(x/\sqrt{2} - \pi/8) + j \sin\,(x/\sqrt{2} - \pi/8)\Big]\Big[1 - \frac{(4\,n^2 - 1^2)}{8\,x\,\sqrt{j}\,|\underline{1}}$$

$$+ \frac{(4\,n^2 - 1^2)\,(4\,n^2 - 3^2)}{(8\,x\,\sqrt{j})^2\,\underline{|2}} - \ldots + (-1)^s \frac{(4\,n^2 - 1^2)\,(4\,n^2 - 3^2)\,\ldots\,\{4\,n^2 - (2\,s - 1)^2\}}{(8\,x\,\sqrt{j})^s\,\underline{|s}} + \ldots \Big] \quad (15)$$

By putting $n = o$,

$$I_0\ (x\,\sqrt{j}) = \text{ber}\,x + j\,\text{bei}\,x = \frac{e^{\frac{x}{\sqrt{2}}}}{\sqrt{2\,\pi\,x}} \Big[\cos\,(x/\sqrt{2} - \pi/8) + j\sin\,(x/\sqrt{2} - \pi/8)\Big] \Big[1 + \frac{1^2}{8\,x\,\sqrt{j}\,\underline{|1}} + \frac{1^2\,.\,3^2}{(8\,x\,\sqrt{j})^2\,\underline{|2}} + \ldots + \frac{1^2\,.\,3^2\,\ldots\,(2\,s-1)^2}{(8\,x\,\sqrt{j})^s\,\underline{|s}} + \ldots\Big] \quad (16)$$

$$\text{Also, ber}'\,x + j\,\text{bei}'\,x = \frac{e^{\frac{x}{\sqrt{2}}}}{\sqrt{2\,\pi\,x}} \Big[\cos\,(x/\sqrt{2} + \pi/8) + j\sin\,(x/\sqrt{2} + \pi/8)\Big] \Big[1 - \frac{(4-1^2)}{8\,x\,\sqrt{j}\,\underline{|1}} + \frac{(4-1^2)\,(4-3^2)}{(8\,x\,\sqrt{j})^2\,\underline{|2}} - \ldots + (-1)^s \frac{(4-1^2)\,(4-3^2)\,\ldots\,\{4-(2\,s-1)^2\}}{(8\,x\,\sqrt{j})^s\,\underline{|s}} + \ldots\Big] \quad (17)$$

$$\text{ker}\,x + j\,\text{kei}\,x = e^{-\frac{x}{\sqrt{2}}} \sqrt{\frac{\pi}{2\,x}} \Big[\cos\,(-x/\sqrt{2} - \pi/8) + j\sin\,(-x/\sqrt{2} - \pi/8)\Big] \Big[1 - \frac{1^2}{8\,x\,\sqrt{j}\,\underline{|1}} + \frac{1^2\,.\,3^2}{(8\,x\,\sqrt{j})^2\,\underline{|2}} + \ldots + (-1)^s \frac{1^2\,.\,3^2\,\ldots\,(2\,s-1)^2}{(8\,x\,\sqrt{j})^s\,\underline{|s}} + \ldots\Big] \quad (18)$$

$$\text{ker}'\,x + j\,\text{kei}'\,x = -\,e^{-\frac{x}{\sqrt{2}}} \sqrt{\frac{\pi}{2\,x}} \Big[\cos\,(-x/\sqrt{2} + \pi/8) + j\sin\,(-x/\sqrt{2} + \pi/8)\Big] \Big[1 + \frac{(4-1^2)}{8\,x\,\sqrt{j}\,\underline{|1}} + \frac{(4-1^2)\,(4-3^2)}{(8\,x\,\sqrt{j})^2\,\underline{|2}} + \ldots + \frac{(4-1^2)\,(4-3^2)\,\ldots\,\{4-(2\,s-1)^2\}}{(8\,x\,\sqrt{j})^s\,\underline{|s}} + \ldots\Big] \quad (19)$$

For obtaining numerical values, put

$$\sqrt{j} = 1/\sqrt{2} + j/\sqrt{2} \qquad \text{as in (12)}$$

$$\text{and}\quad 1/\sqrt{j} = 1/\sqrt{2} - j/\sqrt{2} \qquad (20)$$

Since the general terms of these series are given, any desired number of terms can be evaluated. However, the series are semi-divergent, and there is a limit to the amount of precision which they will give, though this is usually appreciable only for the smaller values of x. It can be proved that the sum of a given number, greater than n, of terms of the series differs from the true value of the function by less than the last term included, and so the series can be used for numerical computation.[6]

As a check on the work described, the writer has used formulas (16) to (19) to calculate the values of the functions tabulated, for $x = 10$, to six significant figures, and the results have agreed with the values in the table.

Other series for large values of x, of which the general terms were not given, have been published by H. G. Savidge.[7] In his formula for η, the term

$$-\frac{21}{128\,\sqrt{2}\,x^3}$$

is evidently a typographical error, since it should be

$$+\frac{21}{128\,\sqrt{2}\,x^3}$$

in order to agree with his preceding calculation on page 108, and also with his previous publication of the first terms of the same series in 1910.[8]

Example. Find the skin effect resistance ratio of a tube in which $t/d = 0.20$ and $m\,t = 3$, t being equal to $(r - q)$, the thickness of the tube in centimeters, and d being equal to $2\,r$, the outside diameter of the tube.

$$\frac{r - q}{2\,r} = 0.2$$

$$r - q = 0.4\,r$$

$$q = 0.6\,r$$

$$m\,(r - q) = 3$$

$$m\,r = 3/0.4 = 7.5$$

$$m\,q = 4.5$$

From equation (4) and Table I,

$$\frac{C + j\,D}{A + j\,B} = -\frac{\text{ber}'\,4.5 + j\,\text{bei}'\,4.5}{\text{ker}'\,4.5 + j\,\text{kei}'\,4.5} = \frac{3.753681 + j\,2.052635}{0.02481454 + j\,0.00771543} = 161.387 + j\,32.5401$$

From equation (10),

$$Z'/R = j\,3.75 \times 0.64 \frac{(5.454962 - j\,29.115712 + 0.258938 + j\,0.264977)}{(24.130125 - j\,14.735602 - 0.012244 - j\,0.388061)}$$

$$= j\,3.75 \times 0.64 \frac{(574.136 - j\,609.403)}{810.397}$$

$$= 1.80475 + j\,1.70031$$

Therefore, $R'/R = 1.80475$

6. Advanced Calculus," by E. B. Wilson, page 398.
7. Report of the British Association for the Advancement of Science, 1916, page 109.
8. *Philosophical Magazine*, Vol. 19, 1910, page 52.

x	ber x	bei x	ber′ x	bei′ x	x	ker x	kei x	ker′ x	kei′ x
0	+1.0	0	0	0	0	+ ∞	−0.785 398 2	− ∞	0
0.1	+0.999 998 438	+0.002 500 000	−0.000 062 500	+0.049 999 974	0.1	+2.420 474 0	−0.776 850 6	−9.960 959 3	+0.145 974 8
0.2	+0.999 975 000	+0.009 999 972	−0.000 499 999	+0.099 999 167	0.2	+1.733 142 7	−0.758 124 9	−4.922 948 5	+0.222 926 8
0.3	+0.999 873 438	+0.022 499 684	−0.001 687 488	+0.149 993 672	0.3	+1.337 218 6	−0.733 101 9	−3.219 865 2	+0.274 292 1
0.4	+0.999 600 004	+0.039 998 222	−0.003 999 911	+0.199 973 334	0.4	+1.062 623 9	−0.703 800 2	−2.352 069 9	+0.309 514 0
0.5	+0.999 023 464	+0.062 493 218	−0.007 812 076	+0.249 918 621	0.5	+0.855 905 9	−0.671 581 7	−1.819 799 8	+0.333 203 8
0.6	+0.997 975 114	+0.089 979 750	−0.013 498 481	+0.299 797 507	0.6	+0.693 120 7	−0.637 449 5	−1.456 538 6	+0.348 164 4
0.7	+0.996 248 828	+0.1[illegible] 448 939	−0.021 433 032	+0.349 562 345	0.7	+0.561 378 3	−0.602 175 5	−1.190 943 3	+0.356 309 5
0.8	+0.993 601 138	+0.159 886 230	−0.031 988 623	+0.399 146 758	0.8	+0.452 882 1	−0.566 367 6	−0.987 335 1	+0.359 042 5
0.9	+0.989 751 357	+0.202 269 363	−0.045 536 553	+0.448 462 528	0.9	+0.362 514 8	−0.530 511 1	−0.825 868 7	+0.357 443 2
1.0	+0.984 381 781	+0.249 566 040	−0.062 445 752	+0.497 396 511	1.0	+0.286 706 2	−0.494 994 6	−0.694 603 9	+0.352 369 9
1.1	+0.977 137 973	+0.301 731 269	−0.083 081 791	+0.545 807 563	1.1	+0.222 844 5	−0.460 129 5	−0.585 905 3	+0.344 521 0
1.2	+0.967 629 156	+0.358 704 420	−0.107 805 642	+0.593 523 499	1.2	+0.168 945 6	−0.426 163 6	−0.494 643 2	+0.334 473 9
1.3	+0.955 428 747	+0.420 405 966	−0.136 972 169	+0.640 338 102	1.3	+0.123 455 4	−0.393 291 8	−0.417 227 4	+0.322 711 8
1.4	+0.940 075 057	+0.486 733 934	−0.170 928 324	+0.686 008 176	1.4	+0.085 126 0	−0.361 664 8	−0.351 055 1	+0.309 641 6
1.5	+0.921 072 184	+0.557 560 062	−0.210 011 017	+0.730 250 674	1.5	+0.052 934 9	−0.331 395 6	−0.294 181 6	+0.295 608 1
1.6	+0.897 891 139	+0.632 725 677	−0.254 544 638	+0.772 739 922	1.6	+0.026 029 9	−0.302 565 5	−0.245 114 7	+0.280 903 8
1.7	+0.869 971 237	+0.712 037 292	−0.304 838 207	+0.813 104 947	1.7	+0.00[illegible] 691 1	−0.275 228 8	−0.202 681 8	+0.265 777 2
1.8	+0.836 721 794	+0.795 261 955	−0.361 182 125	+0.850 926 951	1.8	−0.014 696 1	−0.249 417 1	−0.165 942 4	+0.250 438 5
1.9	+0.797 524 167	+0.882 122 341	−0.423 844 516	+0.885 736 950	1.9	−0.029 661 4	−0.225 142 2	−0.134 128 2	+0.235 065 7
2.0	+0.751 734 183	+0.97[illegible] 291 627	−0.493 067 125	+0.917 013 613	2.0	−0.041 664 5	−0.202 400 1	−0.106 601 0	+0.219 807 9
2.1	+0.698 685 001	+1.065 388 161	−0.569 060 755	+0.944 181 339	2.1	−0.051 106 5	−0.181 172 6	−0.082 823 4	+0.204 789 7
2.2	+0.637 690 457	+1.160 969 944	−0.652 000 244	+0.966 608 614	2.2	−0.058 338 8	−0.161 430 7	−0.062 337 3	+0.190 113 7
2.3	+0.568 048 926	+1.258 528 975	−0.742 018 947	+0.983 606 691	2.3	−0.063 670 5	−0.143 135 7	−0.044 747 9	+0.175 863 8
2.4	+0.489 047 772	+1.357 485 476	−0.839 202 721	+0.994 42[illegible] 643	2.4	−0.067 373 5	−0.126 241 5	−0.029 712 3	+0.162 106 9
2.5	+0.399 968 417	+1.457 182 044	−0.943 583 409	+0.998 268 847	2.5	−0.069 688 0	−0.110 696 1	−0.016 929 8	+0.148 895 4
2.6	+0.300 092 090	+1.556 877 774	−1.055 131 815	+0.994 262 944	2.6	−0.070 825 7	−0.096 442 9	−0.006 135 8	+0.136 268 9
2.7	+0.188 706 304	+1.655 742 407	−1.173 750 173	+0.981 488 365	2.7	−0.070 973 6	−0.083 421 9	+0.002 904 3	+0.124 255 8
2.8	+0.065 112 108	+1.752 850 564	−1.299 264 112	+0.958 965 456	2.8	−0.070 296 3	−0.071 570 7	+0.010 399 0	+0.112 874 8
2.9	−0.071 367 826	+1.847 176 116	−1.431 414 136	+0.925 659 305	2.9	−0.068 939 0	−0.060 825 5	+0.016 534 2	+0.102 136 2
3.0	−0.221 380 249	+1.937 586 785	−1.569 846 632	+0.880 482 324	3.0	−0.067 029 2	−0.051 121 9	+0.021 476 2	+0.092 043 1
3.1	−0.385 531 455	+2.022 839 042	−1.714 104 430	+0.822 297 688	3.1	−0.064 678 6	−0.042 395 5	+0.025 373 8	+0.082 592 2
3.2	−0.564 376 430	+2.101 573 388	−1.863 616 954	+0.749 923 691	3.2	−0.061 984 8	−0.034 582 3	+0.028 360 3	+0.073 775 2
3.3	−0.758 407 012	+2.172 310 131	−2.017 689 996	+0.662 139 131	3.3	−0.059 032 9	−0.027 619 7	+0.030 555 4	+0.065 579 4
3.4	−0.968 038 995	+2.233 445 750	−2.175 495 175	+0.557 689 801	3.4	−0.055 896 6	−0.021 446 3	+0.032 066 2	+0.057 988 1
3.5	−1.193 598 180	+2.283 249 967	−2.336 059 130	+0.435 296 178	3.5	−0.052 639 3	−0.016 002 6	+0.032 988 6	+0.050 982 1
3.6	−1.435 305 322	+2.319 863 655	−2.498 252 527	+0.293 662 421	3.6	−0.049 315 6	−0.011 231 1	+0.033 408 7	+0.044 539 4
3.7	−1.693 259 984	+2.341 297 714	−2.660 778 962	+0.134 686 760	3.7	−0.045 971 7	−0.007 076 7	+0.033 403 0	+0.038 636 4
3.8	−1.967 423 273	+2.345 433 061	−2.822 163 850	−0.052 526 621	3.8	−0.042 646 9	−0.003 486 7	+0.033 040 0	+0.033 248 0
3.9	−2.257 599 466	+2.330 021 882	−2.980 743 427	−0.259 654 097	3.9	−0.039 373 61	−0.000 410 81	+0.032 380 46	+0.028 348 32
4.0	−2.563 416 557	+2.292 690 323	−3.134 653 964	−0.491 137 441	4.0	−0.036 178 85	+0.002 198 40	+0.031 478 49	+0.023 910 62
4.1	−2.884 305 732	+2.230 942 780	−3.281 821 353	−0.748 166 860	4.1	−0.033 084 40	+0.004 385 82	+0.030 381 79	+0.019 908 04
4.2	−3.219 479 832	+2.142 167 987	−3.419 951 224	−1.031 862 169	4.2	−0.030 107 58	+0.006 193 61	+0.029 132 42	+0.016 313 67
4.3	−3.567 910 863	+2.023 647 069	−3.546 519 744	−1.343 251 997	4.3	−0.027 261 77	+0.007 661 27	+0.027 767 30	+0.013 100 84
4.4	−3.928 306 621	+1.872 563 796	−3.658 [illegible]65 306	−1.683 250 947	4.4	−0.024 556 89	+0.008 825 62	+0.026 318 68	+0.010 243 31
4.5	−4.299 086 552	+1.686 017 204	−3.753 681 326	−2.052 634 662	4.5	−0.021 999 88	+0.009 720 92	+0.024 814 54	+0.007 715 43
4.6	−4.678 356 937	+1.461 036 836	−3.828 010 348	−2.452 012 698	4.6	−0.019 595 03	+0.010 378 86	+0.023 279 08	+0.005 492 26
4.7	−5.063 885 587	+1.194 600 797	−3.878 239 739	−2.881 799 197	4.7	−0.017 344 41	+0.010 828 72	+0.021 733 00	+0.003 549 76
4.8	−5.453 076 175	+0.883 656 854	−3.900 599 216	−3.342 181 300	4.8	−0.015 248 19	+0.011 097 40	+0.020 193 91	+0.001 864 78
4.9	−5.842 942 442	+0.525 146 811	−3.891 060 511	−3.833 085 297	4.9	−0.013 304 90	+0.011 209 53	+0.018 676 61	+0.000 415 22
5.0	−6.230 082 479	+0.116 034 382	−3.845 339 473	−4.354 140 518	5.0	−0.011 511 73	+0.011 187 59	+0.017 193 40	−0.000 819 98
5.1	−6.610 653 357	−0.346 663 218	−3.758 900 943	−4.904 640 985	5.1	−0.009 864 74	+0.011 052 01	+0.015 754 36	−0.001 860 79
5.2	−6.980 346 403	−0.865 839 727	−3.626 966 748	−5.483 504 900	5.2	−0.008 359 11	+0.010 821 28	+0.014 367 57	−0.002 726 05
5.3	−7.334 363 435	−1.444 260 151	−3.444 527 187	−6.089 232 022	5.3	−0.006 989 28	+0.010 512 06	+0.013 039 35	−0.003 433 49
5.4	−7.667 394 351	−2.084 516 693	−3.206 356 389	−6.719 859 076	5.4	−0.005 749 13	+0.010 139 29	+0.011 774 46	−0.003 999 69
5.5	−7.973 [illegible]96 451	−2.788 980 155	−2.907 031 958	−7.372 913 333	5.5	−0.004 632 16	+0.009 716 31	+0.010 576 33	−0.004 440 16
5.6	−8.246 575 962	−3.559 746 593	−2.540 959 318	−8.045 364 552	5.6	−0.003 631 56	+0.009 254 96	+0.009 447 17	−0.004 769 28
5.7	−8.479 372 252	−4.398 579 111	−2.102 401 197	−8.733 575 532	5.7	−0.002 740 38	+0.008 765 72	+0.008 388 18	−0.005 000 41
5.8	−8.664 445 263	−5.306 844 640	−1.585 512 696	−9.433 251 539	5.8	−0.001 951 58	+0.008 257 74	+0.007 399 67	−0.005 145 84
5.9	−8.793 666 753	−6.285 445 623	−0.9[illegible]4 382 394	−10.139 388 963	5.9	−0.001 258 12	+0.007 739 02	+0.006 481 21	−0.005 216 89
6.0	−8.858 315 966	−7.334 746 541	−0.293 079 967	−10.846 223 584	6.0	−0.000 653 04	+0.007 216 49	+0.005 631 71	−0.005 223 92
6.1	−8.849 080 413	−8.454 495 269	+0.494 289 242	−11.547 178 908	6.1	−0.000 129 53	+0.006 696 06	+0.004 849 57	−0.005 176 37
6.2	−8.756 062 474	−9.643 739 286	+1.383 522 213	−12.234 815 078	6.2	+0.000 319 05	+0.006 182 75	+0.004 132 75	−0.005 082 83
6.3	−8.568 792 593	−10.900 736 825	+2.380 248 360	−12.900 778 962	6.3	+0.000 699 12	+0.005 680 77	+0.003 478 86	−0.004 951 05
6.4	−8.276 249 873	−12.222 863 128	+3.489 851 325	−13.535 756 059	6.4	+0.001 016 83	+0.005 193 58	+0.002 885 23	−0.004 788 03
6.5	−7.866 890 928	−13.606 512 001	+4.717 382 012	−14.129 423	6.5	+0.001 278 080	+0.004 723 992	+0.002 348 995	−0.004 600 032
6.6	−7.328 687 885	−15.046 992 991	+6.067 462 487	−14.670 413	6.6	+0.001 488 446	+0.004 274 219	+0.001 867 130	−0.004 392 632
6.7	−6.649 176 464	−16.538 424 538	+7.544 180 362	−15.146 266	6.7	+0.001 653 215	+0.003 845 947	+0.001 436 521	−0.004 170 782
6.8	−5.815 515 115	−18.073 623 609	+9.150 973 359	−15.543 406	6.8	+0.001 777 354	+0.003 440 398	+0.001 053 999	−0.003 938 849
6.9	−4.814 556 200	−19.643 992 365	+10.890 503 759	−15.847 109	6.9	+0.001 865 512	+0.003 058 385	+0.000 716 382	−0.003 700 651
7.0	−3.632 930 243	−21.239 402 580	+12.764 522 560	−16.041 489	7.0	+0.001 922 022	+0.002 700 365	+0.000 420 510	−0.003 459 509
7.1	−2.257 144 280	−22.848 078 597	+14.773 723 174	−16.109 484	7.1	+0.001 950 901	+0.002 366 486	+0.000 163 267	−0.003 218 285
7.2	−0.673 695 379	−24.456 479 797	+16.917 584 633	−16.032 856	7.2	+0.001 955 861	+0.002 056 629	−0.000 058 386	−0.002 979 421
7.3	+1.130 799 653	−26.049 183 639	+19.194 204 342	−15.792 207	7.3	+0.001 940 312	+0.001 770 454	−0.000 247 403	−0.002 744 978
7.4	+3.169 457 312	−27.608 770 523	+21.600 120 535	−15.367 001	7.4	+0.001 907 373	+0.001 507 429	−0.000 406 628	−0.002 516 671
7.5	+5.454 962 184	−29.115 711 867	+24.130 124 710	−14.735 602	7.5	+0.001 859 888	+0.001 266 868	−0.000 538 787	−0.002 295 904
7.6	+7.999 382 494	−30.548 262 965	+26.777 064 473	−13.875 334	7.6	+0.001 800 431	+0.001 047 959	−0.000 646 478	−0.002 083 800
7.7	+10.813 965 476	−31.882 362 359	+29.531 637 360	−12.762 551	7.7	+0.001 731 326	+0.000 849 790	−0.000 732 165	−0.001 881 234
7.8	+13.908 911 711	−33.091 539 670	+32.382 176 399	−11.372 739	7.8	+0.001 654 654	+0.000 671 373	−0.000 798 170	−0.001 688 855
7.9	+17.293 127 645	−34.146 833 988	+35.314 428 336	−9.680 623	7.9	+0.001 572 275	+0.000 511 664	−0.000 846 677	−0.001 507 120
8.0	+20.973 955 611	−35.016 725 165	+38.311 325 701	−7.660 318	8.0	+0.001 485 834	+0.000 369 584	−0.000 879 724	−0.001 336 313
8.1	+24.956 880 800	−35.667 080 514	+41.352 754 078	−5.285 490	8.1	+0.001 396 782	+0.000 244 032	−0.000 899 210	−0.001 176 567
8.2	+29.245 214 796	−36.061 119 681	+44.415 316 208	−2.529 555	8.2	+0.001 306 386	+0.000 133 902	−0.000 906 891	−0.001 027 888
8.3	+33.839 755 432	−36.159 400 616	+47.472 094 831	+0.634 098	8.3	+0.001 215 743	+0.000 038 090	−0.000 904 388	−0.000 890 168
8.4	+38.738 422 961	−35.919 829 830	+50.492 416 438	+4.231 841	8.4	+0.001 125 797	−0.000 044 491	−0.000 893 190	−0.000 763 209
8.5	+43.935 872 751	−35.297 700 300	+53.441 618 430	+8.289 519	8.5	+0.001 037 349	−0.000 114 902	−0.000 874 656	−0.000 646 733
8.6	+49.423 084 977	−34.245 760 640	+56.280 822 496	+12.832 116	8.6	+0.000 951 070	−0.000 174 175	−0.000 850 022	−0.000 540 398
8.7	+55.186 932 099	−32.714 319 308	+58.966 717 374	+17.883 387	8.7	+0.000 867 511	−0.000 223 306	−0.000 820 407	−0.000 443 813
8.8	+61.209 725 224	−30.651 387 879	+61.451 354 516	+23.465 444	8.8	+0.000 787 120	−0.000 263 248	−0.000 786 819	−0.000 356 543
8.9	+67.468 740 848	−28.002 867 538	+63.681 960 575	+29.598 302	8.9	+0.000 710 249	−0.000 294 910	−0.000 750 159	−0.000 278 127
9.0	+73.935 729 857	−24.712 783 168	+65.600 770 999	+36.299 384	9.0	+0.000 637 164	−0.000 319 153	−0.000 711 231	−0.000 208 079
9.1	+80.576 411 145	−20.723 569 533	+67.144 889 467	+43.582 976	9.1	+0.000 568 055	−0.000 336 788	−0.000 670 745	−0.000 145 903
9.2	+87.349 952 674	−15.976 414 197	+68.246 178 293	+51.459 634	9.2	+0.000 503 046	−0.000 348 579	−0.000 629 326	−0.000 091 093
9.3	+94.208 443 358	−10.411 661 917	+68.831 185 381	+59.935 547	9.3	+0.000 442 203	−0.000 355 236	−0.000 587 517	−0.000 043 145
9.4	+101.096 359 718	−3.969 285 324	+68.821 113 743	+69.011 850	9.4	+0.000 385 540	−0.000 357 420	−0.000 545 789	−0.000 001 559
9.5	+107.950 031 881	+3.410 573 282	+68.131 8[illegible]0 035	+78.683 888	9.5	+0.000 333 029	−0.000 355 743	−0.000 504 544	+0.000 034 158
9.6	+114.697 114 173	+11.786 984 189	+66.673 989 017	+88.940 434	9.6	+0.000 284 604	−0.000 350 768	−0.000 464 122	+0.000 064 4[illegible]5
9.7	+121.256 066 255	+21.217 531 810	+64.353 071 286	+99.762 855	9.7	+0.000 240 168	−0.000 343 010	−0.000 424 806	+0.000 089 887
9.8	+127.535 651 521	+31.757 530 896	+61.069 692 033	+111.124 240	9.8	+0.000 199 598	−0.000 332 940	−0.000 386 830	+0.000 110 811
9.9	+133.434 460 262	+43.459 152 933	+56.719 839 030	+122.988 479	9.9	+0.000 162 751	−0.000 320 983	−0.000 350 379	+0.000 127 684
10.0	+138.840 465 942	+56.370 458 554	+51.195 258 394	+135.309 302	10.0	+0.000 129 466	−0.000 307 524	−0.000 315 597	+0.000 140 914

This is seen at once to check with the curve for $t/d = 0.20$, reading at $m\,t = 3$, in Fig. 3, TRANSACTIONS A. I. E. E., 1918, page 1384, (reference 1).

To check the result with Fig. 1, JOURNAL of the A. I. E. E., March 1922, page 204, (reference 2), we have f/R_{dc} (in ohms per 1000 ft.)

$$= \frac{\pi\,(r^2 - q^2)}{\rho}\;\frac{f \times 10^9 \times 0.3937}{12000}$$

and

$$m^2\,t^2 = \frac{8\,\pi^2 f\,(r - q)^2}{\rho}$$

where the dimensions are in centimeters and ρ is in absolute units.

$$\text{Therefore,}\quad \sqrt{f/R_{dc}} = \sqrt{\frac{9 \times 10^9 \times 0.3937 \times 4}{8\,\pi \times 12000}} = 216.8$$

The value of R'/R_{dc} read from the curve is seen to be 1.805.

TO IMPROVE LIGHTING OF POSTOFFICES

A recent issue of the *Electrical World* gives an interesting account of an investigation of lighting conditions in postoffices which has been conducted by the Office of Industrial Hygiene and Sanitation of the United States Health Service at the special request of Postmaster-General Work. A report of this survey has been submitted recommending the establishment of a standard system of lighting in all postoffices which would provide a level of 10 foot-candles. The report maintains that millions of dollars will be saved through increased speed in the work of postal employes provided that a complete change is effected in the illumination of workrooms of postoffices throughout the country.

Virtually all the work performed in postoffices with the exception of that of laborers depends primarily upon the use of the eyes, making the question of illumination of paramount importance in decreasing or increasing its rapidity and accuracy. Conducting a thorough and technical study of lighting over a long period of time at two representative postoffices, one modern and the other of the old type, the experts observed almost five thousand postal workers employed constantly in handling the mails both under artificial and natural light.

They found that illumination in many postoffices was low in intensity and unsatisfactory in quality. In some instances it fell below the requirements provided by the state code of laws and below the artificial light furnished employes in private industries doing similar work. A study of the relationship between the volume of the illumination and the strain on the eyes of workers revealed the fact that there were more eye defects among employes working under the average illumination of 2 to 3 foot-candles in the old postoffice than under the 3 to 4 foot-candles in the new postoffice. Sorting and separating mail in the basements of postoffice buildings was especially discountenanced except in extreme emergencies.

In the speed and accuracy tests it was found that for the letter separators there was an average increase in speed, or decrease in the times of separation, of at least 4.4 per cent when the illumination was raised from 3.6 to 8 foot-candles. Assuming that the same relative increase of speed would prevail in all the divisions of the postoffice where these tests were made under the same relative increase in illumination, an annual net saving, after deducting increased cost for lamps and energy, of about $109,000 was indicated in this postoffice alone.

The investigators recommended that there should be installed in the general workrooms and office systems of totally inclosing units of the diffusing or light-directing type, giving a general intensity when first installed of 10 foot-candles everywhere on a horizontal working plane 45 inches above the floor. It was further recommended that all local lighting should be done away with.

It was recommended that lighting units installed in the general workrooms of the postoffice should have a surface brightness not exceeding 2.5 candle power per square inch when used with a light source emitting 3100 lumens and that the surface brightness of the units for the offices of the postoffice should not exceed 2 candle power per square inch when used with the same sized light source.

The report indicates that units for general workrooms and offices should be such in number and so spaced that the brightness of the units measured in lumens per square foot would not be more than one hundred times as great as the intensity of the illumination, measured in foot-candles, produced by them on a horizontal plane 45 inches above the floor.

Recommendations on the care of the lighting system and a disquisition on modern methods of illumination are included in the report.

CRYSTALLINE FORM OF ELECTRODEPOSITED METALS

A paper entitled "Notes on the Crystalline Form of Electrodeposited Metals" has been prepared by members of the Bureau's staff for presentation at the Fall meeting of the American Electrochemical Society. The purpose of this paper is to present a simple theory on the mechanism of electrodeposition and a classification of structures which the Bureau believes will be helpful in further studies in this field.

The paper is of special interest in emphasizing the large amount of work still to be done upon the fundamental principles of electrodeposition and the need of applying all possible methods of attack, including the study of microstructure and x-ray analysis. It is hoped that during the next few years there will be an opportunity for more extensive study of these fundamental principles.

Short-Circuit Forces on Reactor Supports

BY R. E. DOHERTY and F. H. KIERSTEAD
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Review of the Subject.—*The mechanical stress in the supporting members of any structure or apparatus under steady state is determined by the dimensions of the member and the magnitude of the resultant applied force. Under accelerated motion, however, an additional factor enters, namely, the reaction of the mass; and if the supporting members in this case are resilient, that is, spring-like, then this becomes still another factor which enters the problem of determining the mechanical stress produced by a given impressed force.*

The determination of the stress in the holding device (bolts, etc.) of reactors under short-circuit condition is just such a problem. If any motion whatever is permitted under this condition, the factors of mass and resilience are active.

This paper gives a theoretical analysis of the problem, and shows that if any motion is permitted, thus allowing the factors of mass and resilience to become active, then the maximum stress may be significantly increased above that for no motion. Illustrative calculations show that this increase in practical cases may be of the order of 25 per cent. On the other hand, if motion of the reactors is prevented by sufficient initial bolt tension, or otherwise, then the maximum stress in the holding device obviously need be only as great as that corresponding to the maximum instantaneous peak of the electromagnetic force.

A NUMBER of papers[1] has appeared in which the problem of the electromagnetic force between electric conductors or between coils, has been analyzed. The stresses, however, which such forces create in the members on which they act, are not determined merely by the value of the electromagnetic force and the dimensions of the members, as would be the case with a steady applied force, but also depend in a large measure upon other factors. Hence the analysis of such stresses is a separate problem in which the electromagnetic force is only one of a number of factors.

Scope

The present paper investigates, in a theoretical way, the character of the force which is required to hold the reactor as a whole, against short-circuit forces. Unlike the problems covered by the foregoing papers, which were concerned with the character of the electromagnetic force itself, the present investigation assumes that this force is given, and inquires into the nature of the stresses it produces in the holding device, such as bolts, etc. In other words, the problem is of a purely mechanical nature.

As such, it is the same, in fundamental respects, as a number of other problems in engineering which involve the factors of mass, resilience and a periodic impressed force.

For instance: Fly wheels for synchronous machines mechanically connected to reciprocating apparatus[2]; torsional strain of a turbo-generator shaft during generator short circuit[3]; the behavior of bus bars carrying short-circuit current[4]; the behavior of certain types of engine governors, etc. This class of phenomena is best illustrated by the simple case of the behavior of a weight, suspended by a spring, and acted upon by an alternating-current electromagnet.

Mathematically, the problem is identical with a much wider range of phenomena; that is, in addition to the above cases it involves the same form of differential equation[5] as a number of familiar problems in electrical engineering. For instance: The electric circuit containing resistance, inductance and capacity in series[6]; the series circuit involving an exciter and alternator field.[7]

The present investigation, therefore, does not deal with a new phenomenon; it merely starts with certain assumptions, which appear reasonable, and which written down mathematically, give a well known differential equation, and then applies the solution to the physical conditions of the problem. This makes it possible, within specified limits, to answer a number of questions regarding the character of the force on the holding device.

In a later paper the authors expect to present some experimental data regarding these forces.

Equations

The equations are set up under the following assumptions:

Supporting floors rigid.
Single-phase short circuit.
Current wave completely off-set.
No transients; that is, damping neglected.
Reactor unit, including concrete, etc. rigid body.
Initial tension on holding bolts same on all bolts.

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1. Some of which are listed in the bibliography.

2. "Design of Fly Wheels for Reciprocating Machinery Connected to Synchronous Generators or Motors," by R. E. Doherty and R. F. Franklin, A. S. M. E. *Transactions*, 1920, V. 42, pp. 523-567.

3. "Mechanical Effects of Electrical Short Circuits," by S. H. Weaver, *G. E. Review*, November 1915, V. 18, pp. 1066-1074.

4. "Uber die Mechanischen Wirkungen des Plötzlichen Kurzschluss-stromes von Synchronmaschinen" by J. Biermanns, *Archiv für Electrotecknik*, IX, 1920, pp. 326-340.

5. Second order, linear.

6. "Theory and Calculation of Transient Electric Phenomena and Oscillations," by C. P. Steinmetz, 3rd Ed., p. 48.

7. "Exciter Instability," by R. E. Doherty, JOURNAL A. I. E. E., Oct. 1922, pp. 731-744.

Presented at the Spring Convention of the A. I. E. E., Pittsburgh Pa., April 24-26, 1923.

Reactors connected to give attraction.
Center lines of coils coincide, as in Fig. 1.
Displacement x sufficient to permit free movement of the reactor B, that is, no interference by supporting floor.
Magnetic force proportional to square of the current, other factors being constant.

Let
M = mass of reactor
i = current in reactor coils (amperes)
x = displacement of reactor B above floor (feet)
f_s = force due to bolts (lb.)
f_c = force due to currents (lb.)
W = weight of reactor = $g\,M$ (lb.)
g = gravity = 32.2 feet/sec.^{2}
k = lb. force required to elongate bolts one foot
f_0 = total force due to initial tension in bolts at $x = 0$
e = modulus of elasticity of bolt material = 30×10^6 for steel
a = total cross section of bolts in sq. inches
l = free length (inches) of bolts under tension
t = time in seconds.

The sum of all forces acting on the mass must equal zero. That is,

$$\Sigma \text{ forces} = 0 \tag{1}$$

Thus
$$f_c - M\frac{d^2 x}{d t^2} + f_s - W = 0 \tag{2}$$

But
$$f_s = -(f_o + k\,x) \tag{3}$$

Where
$$k = 12\,e\,a/l \tag{3a}$$

Therefore
$$f_c - M\frac{d^2 x}{d t^2} - f_o - k\,x - W = 0$$

or
$$\frac{d^2 x}{d t^2} + k\,x/M = f_c/M - \frac{(f_o + W)}{M} \tag{4}$$

The force f_c is proportional to the square of the current. Thus, let[8]

$$f_c = K\,i^2 \tag{5}$$

The current i is of the form,

$$i = I_0\,(1 - \cos\omega\,t) \tag{6}$$

as shown in Fig. 2.
where I_o = maximum value of a. c. component of the current i
$\omega = 2\,\pi\,f$
f = electrical frequency.

Substituting (6) in (5).

$$f_c = K\,I_0^2\,(1.5 - 2\cos\omega\,t + 0.5\cos 2\,\omega\,t) \tag{7}$$

Substituting this in (4),

$$\frac{d^2 x}{d t^2} + k\,x/M = -2\frac{K\,I_o^2}{M}(\cos\omega\,t - 0.25\cos 2\,\omega\,t) + 1.5\frac{K\,I_o^2}{M} - \frac{f_o + W}{M}$$

Let
$$\frac{K\,I_o^2}{M} = D \tag{8}$$

$$k/M = \alpha^2 \tag{9}$$

and
$$1.5\,D - \frac{f_o + W}{M} = E \tag{10}$$

Then the differential equation becomes,

$$\frac{d^2 x}{d t^2} + \alpha^2 x = -2\,D\cos\omega\,t + 0.5\,D\cos 2\,\omega\,t + E \tag{11}$$

The solution of this equation will be in four parts as follows:

$$x = x_1 + x_2 + x_3 + x_4 \tag{12}$$

where, x_1 is given by the complementary function

$$\frac{d^2 x_1}{d t^2} + \alpha^2 x_1 = 0 \tag{13}$$

x_2 is given by the particular solution,

$$\frac{d^2 x_2}{d t^2} + \alpha^2 x_2 = -2\,D\cos\omega\,t \tag{14}$$

x_3, by the particular solution,

$$\frac{d^2 x_3}{d t^2} + \alpha^2 x_3 = 0.5\,D\cos 2\,\omega\,t \tag{15}$$

and x_4, by

$$\frac{d^2 x_4}{d t^2} + \alpha^2 x_4 = E \tag{16}$$

Solution of (13) is

$$x_1 = C_1\cos\alpha\,t + C_2\sin\alpha\,t \tag{17}$$

Solution of (14) and (15) is obtained by temporarily using vectors and substituting

$$\left.\begin{aligned} \frac{d}{d t}x &= p\,x = j\,\omega\,x \\ \frac{d^2}{d t^2}x &= p^2 x = -\omega^2 x \end{aligned}\right\} \tag{18}$$

since a cosine function only is involved. Thus, in (14)

$$x_2\,(-\omega^2 + \alpha^2) = -2\,D$$

and
$$x_2 = \frac{2\,D}{\omega^2 - \alpha^2}$$

or
$$x_2 = \frac{2\,D\cos\omega\,t}{\omega^2 - \alpha^2} \tag{19}$$

and similarly
$$x_3 = -\frac{0.5\,D\cos 2\,\omega\,t}{4\,\omega^2 - \alpha^2} \tag{20}$$

Solution of (16) is $x_4 = E/\alpha^2$ (21)

Therefore by (12)

$$x = C_1\cos\alpha\,t + C_2\sin\alpha\,t + \frac{2\,D\cos\omega\,t}{\omega^2 - \alpha^2} - \frac{0.5\,D\cos 2\,\omega\,t}{4\,\omega^2 - \alpha^2} + E/\alpha^2 \tag{22}$$

8. The assumption is made that no deflection will be large enough to alter the value of K, that is, K = constant.

Thus the solution involves two constants, C_1 and C_2, which must be determined by the boundary conditions, such as the value of x and of $\frac{dx}{dt}$ at some particular value of t. In other words, with the constant value of displacement represented by the last term of (**22**) and with the definite functions of time represented by the 3rd and 4th terms, the constants C_1 and C_2 must be of such values that the sum of all terms must give the known boundary conditions. Or further, for instance, if $x = 0$ at $t = 0$, then the sum of the first two terms must be equal to minus the sum of the last three terms. It follows that if the boundary conditions happen to be such that they are given by the last three terms then C_1 and C_2 must be zero—that is, there would be no oscillation at the natural frequency

$$n = \frac{\alpha}{2\pi}$$

as discussed later.

To illustrate the application of equation (**22**) the following Cases will be considered.

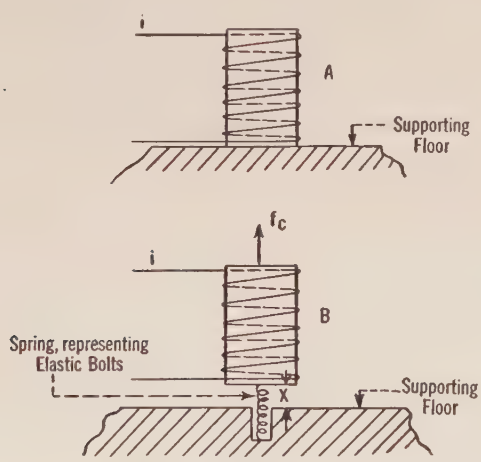

FIG. 1

Case 1. Physical location of reactors as shown in Fig. 1. Hypothetical case in which the interference of the floor to the free movement of the reactor is neglected.

Case 2. Same as *Case* 1 except that the effect of the floor is considered.

Case 3. Same as *Case* 1 except that the frequency of the electrical force is doubled.

Case 4. Same as *Case* 2 except that the frequency of the electrical force is doubled.

Case 5. Reactors rigidly fastened to I-beams instead of being bolted to a rigid floor as in the foregoing Cases.

DATA

The following data are used in all Cases excepting *Case* 5;

$$W = 1000 \text{ lb.}$$
$$M = W/g = 1000/32.2 = 31$$

Average value of magnetic force is

$$1.5\, K\, I_o^2 = 10 \times W = 10{,}000 \text{ lb.}$$

Thus, the peak value of the magnetic force, by equation 7,

$$= 4\, K\, I_o^2 = 26{,}640 \text{ lb.}$$

and,

$$\frac{K\, I_o^2}{W} = \frac{K\, I_o^2}{g\, M} = 10/1.5 = 6.66$$
$$\frac{K\, I_o^2}{M} = 6.66\, g = 214$$

Four steel bolts, each one square inch in cross-section and 10 inches free length

$$e = 30 \times 10^6 \text{ lb./sq. in. for steel}$$

Thus, by (**3a**)

$$k = 144 \times 10^6 \text{ lb./ft. elongation of bolts.}$$

By (**25**)

$$\alpha = \sqrt{\frac{144 \times 10^6}{31}} = 2160 \cong 2260 \text{ rad./sec.}^{9}$$
$$n \cong \frac{2260}{2\pi} = 360 \text{ cycles/sec.}$$

The above data may not be representative but they will serve for illustration of the application of the equations.

CASE 1

The physical relation of the reactors is shown in Fig. 1. The integration constants C_1 and C_2 are determined under the following hypothetical assumption: At $t = 0$, that is, at the moment the short circuit occurs, a shim between the reactor and the floor is suddenly withdrawn, thus permitting free motion of the reactor under the influence of all the forces assumed in the equation. This, of course, is far from a practical case, but it is of interest, and perhaps may be of importance to some readers, in helping to form an idea of the general character of the phenomenon, and in leading up to the second case, in which the effect of the floor is taken into account.

The integration constants are determined, therefore, from the boundary conditions that at

$$t = 0,\ x = 0 \text{ and } \frac{dx}{dt} = 0$$

Thus, from (**22**)

$$C_1 + \frac{2D}{\omega^2 - \alpha^2} - \frac{0.5\, D}{4\,\omega^2 - \alpha^2} + E/\alpha^2 = 0$$

and

$$C_2\, \alpha = 0$$

Therefore

$$\left.\begin{aligned} C_1 &= -\frac{2D}{\omega^2 - \alpha^2} + \frac{0.5\, D}{4\,\omega^2 - \alpha^2} - E/\alpha^2 \\ C_2 &= 0 \end{aligned}\right\} \quad (\mathbf{23})$$

9. In order to have $n = 3f$, thus facilitating computations.

Substituting in (**22**)

$$x = \left[-\frac{2\,D}{\omega^2 - \alpha^2} + \frac{0.5\,D}{4\,\omega^2 - \alpha^2} - E/\alpha^2 \right] \cos \alpha\, t$$

$$+ \frac{2\,D}{\omega^2 - \alpha^2} \cos \omega\, t - \frac{0.5\,D}{4\,\omega^2 - \alpha^2} \cos 2\,\omega\, t + E/\alpha^2 \qquad (\mathbf{24})$$

The angular velocity of the natural oscillations is, by (**9**) and (**24**)

$$\alpha = \sqrt{k/M} = 2\,\pi\, n \qquad (\mathbf{25})$$

where n = oscillations per second

Also $\omega = 2\,\pi\, f$

Substituting these relations and also (**8**) (**9**) and (**10**) in (**24**), the final equation for x becomes,

$$x = \left[2\frac{K\,I_o^2}{M\,\omega^2} \left\{ -\frac{1}{1-(n/f)^2} + \frac{0.0625}{1-\left(\frac{n}{2f}\right)^2} \right\} - \frac{1.5\,K\,I_o^2 - (f_o + W)}{k} \right] \cos \alpha\, t$$

$$+ 2\frac{K\,I_o^2}{M\,\omega^2} \left\{ \frac{\cos \omega\, t}{1-(n/f)^2} - \frac{0.0625 \cos 2\,\omega\, t}{1-\left(\frac{n}{2f}\right)^2} \right\}$$

$$+ \frac{1.5\,K\,I_o^2 - (f_o + W)}{k} \qquad (\mathbf{26})$$

Equation (**26**) is made up of two parts:

x_a = complex oscillation, given by the trigonometric terms, the average of which, over complete cycles, is zero.

and x_b = a constant deflection, determined by the difference between a constant force[10] $1.5\,K\,I_o^2$ and the sum of the weight W and initial bolt tension f_o.

The magnitudes of the different components of the complex oscillation are dependent upon the ratio of the frequency n of natural oscillations to the frequency f of the electrical system, and the second harmonic $2\,f$.

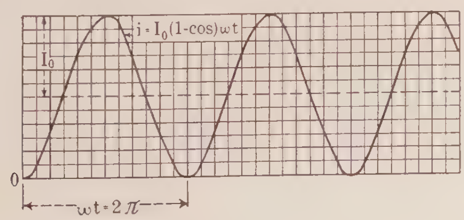

Fig. 2

The constant component x_b of the total deflection x is obviously

$$x_b = \frac{1.5\,K\,I_o^2 - (f_o + W)}{k} \qquad (\mathbf{27})$$

10. It is interesting to consider the value of current i, on which this force depends. By equation (5), force is

$$K\,i^2$$

But here $i_1^2 = 1.5\,I_o^2$, that is $i_1 = \sqrt{1.5\,I_o}$. This is the root-mean-square of the total current during the first cycle. That is, the steady, or average, deflection is determined by the root-mean-square current.

This will evidently be zero when

$$f_o + W = 1.5\,K\,I_o^2$$

or, when

$$f_o = 1.5\,K\,I_o^2 - W \qquad (\mathbf{28})$$

That is, x_b will be zero if the initial bolt tension f_o is the difference between the magnetic force $1.5\,K\,I_o^2$ and the weight W.

Assuming the condition given by (**28**), then equation (**26**) becomes

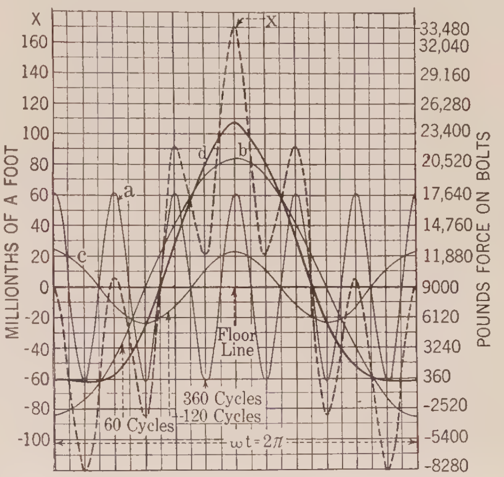

Fig. 3—Case I. Hypothetical Case. Assumes Oscillation About Floor Line as Average Position

$x = 10^{-6}$ (0.5 cos 2260 t − 85.5 cos 377 t + 24 cos 754 t)

$4\,k\,I_0^2 \simeq$ 26,640 lb. a = 1st term, b = 2nd term, c = 3rd term

$d = b + c$, $x = a + b + c$

$$x = 2\frac{K\,I_o^2}{M\,\omega^2} \left[\left\{ -\frac{1}{1-(n/f)^2} + \frac{0.0625}{1-\left(\frac{n}{2f}\right)^2} \right\} \cos \alpha\, t + \left\{ \frac{\cos \omega\, t}{1-(n/f)^2} - \frac{0.0625 \cos 2\,\omega\, t}{1-\left(\frac{n}{2f}\right)^2} \right\} \right] \qquad (\mathbf{29})$$

The electrical frequency is taken as 60 cycles. Thus,

$$\omega = 2\,\pi\, f = 377 \text{ rad./sec.}$$

Other data are given under "Data" above.

Thus $n/f \cong 6.0$

and $\dfrac{n}{2\,f} \cong 3.0$

These values substituted in (**29**) give,

$$x = 2\frac{6660}{31 \times 377^2} \left[\left\{ -\frac{1}{1-(360/60)^2} + \frac{0.0625}{1-(360/120)^2} \right\} \cos 2260\, t + \left\{ \frac{\cos \omega\, t}{1-(360/60)^2} - \frac{0.0625 \cos 2\,\omega\, t}{1-(360/120)^2} \right\} \right]$$

Thus $x = (61.5 \cos 2260\, t - 85.5 \cos 377\, t + 24 \cos 754\, t)\, 10^{-6}$

This is plotted as *Case* 1 in Fig. 3.

It will be noted that the maximum force on the bolts is 33,480 lb., whereas the maximum magnetic force is 26,640. That is, permitting free motion *increases* the stress on the bolts in this particular case. It must be remembered that curve x is the displacement under the hypothetical assumption that the average force is just balanced by the weight and initial bolt tension, and that the floor does not interfere with the free movement of the reactor. It will be observed that the amplitude of a is just equal, and opposite, to d at t = zero. If the initial conditions had been that at $t = 0$, $x = -61.5$ millionths of a foot instead of zero, and that

$$\frac{d\,x}{d\,t} = 0, \text{ as before,}$$

then, obviously there would have been no term of 360 cycles. The curve for x would merely be d under those conditions.

CASE 2

How does the floor modify the situation? Obviously if $(f_0 + W)$ is greater than the maximum instantaneous value of magnetic force, there can be no motion of the reactor. If it is less, the floor prevents movement until the instantaneous value of the magnetic force becomes greater than the sum

$$f_0 + W$$

Thus to get the actual movement of the reactor, new integration constants, C_1 and C_2, must be determined for the following known conditions:

$$f_c = f_o + W$$

$$x = O$$

$$\frac{d\,x}{d\,t} = O$$

Since $\quad f_o + W = 1.5\,K\,I_o^2$

and $\quad f_c = K\,I_o^2\,(1.5 - 2\cos\omega\,t + 0.5\cos 2\,\omega\,t)$

by equation (7)

it follows that

$$f_c = f_o + W \text{ at } \omega\,t = 103°$$

Referring to equation (22) the constant term

$$E/\alpha^2$$

is zero as in *Case* 1. The 3rd and 4th terms are naturally also the same. Thus by (22) and (29) and the given data, the new equation is

$$x = (C_1\cos 2260\,t + C_2\sin 2260\,t - 85.5\cos 377\,t + 24\cos 754\,t)\,10^{-6}$$

and

$$\frac{d\,x}{d\,t} = (-2260\,C_1\sin 2260\,t + 2260\,C_2\cos 2260\,t + 32200\sin 377\,t - 18100\sin 754\,t)\,10^{-6}$$

When $\quad \omega\,t = 103$ degrees

$\alpha\,t = 6 \times 103 = 618$ degrees

$2\,\omega\,t = 206$ degrees

$\sin 618° = -0.978$

$\cos 618° = -0.208$

$\cos 103° = -0.225$

$\sin 103° = +0.974$

$\cos 206° = -0.899$

$\sin 206° = -0.438$

$$x = 0 = -0.208\,C_1 - 0.978\,C_2 - 85.5\,(-0.225) + 24.0\,(-0.899) = -0.208\,C_1 - 0.978\,C_2 - 2.32$$

and

$$\frac{d\,x}{d\,t} = 0 = -2260\,C_1\,(-0.978) + 2260\,C_2\,(-0.208) + 32200\,(0.974) - 18100\,(-0.438) = 2210\,C_1 - 470\,C_2 + 39280$$

Solving these equations simultaneously,

$$C_1 = -17.5$$

$$C_2 = 1.3 = \text{negligible}$$

Therefore the new equation for the actual motion of the reactor is

$$x = (-17.5\cos 2260\,t - 85.5\cos 377\,t + 24\cos 754\,t)\,10^{-6}$$

This is plotted as *Case* 2, in Fig. 4. Thus the reactor would leave the floor at about 0.3 cycle of $\omega\,t$ after the short circuit occurs, reach a maximum displacement of 106×10^{-6} feet, and return to the floor at about 0.7 cycle, thus being clear of the floor for about 0.4 cycle.

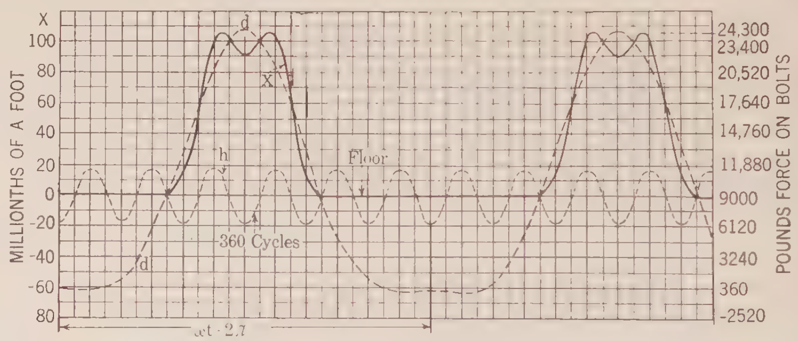

FIG. 4—CASE 2. REACTOR SUPPORTED BY FLOOR

Curve shows actual motion of reactor, assuming same initial high tension on bolts as in Case 7.

$x = 10^{-6}\,(-17.5\cos 2260\,t - 85.5\cos 377\,t + 24\cos 754\,t)$

$x = d + h$ for values of $d >$ zero; d = same as in Fig. 2

$4\,k\,I_0^2 = 26{,}640$ lb.

It would then remain on the floor, that is, at $x = 0$, until the instantaneous value of magnetic force again equals $(f_0 + W)$, which would obviously occur at about 0.6 cycle after the reactor returned to the floor. There would therefore be a series of "jumps", one each cycle, as shown by the heavy curve x Fig. 4. Actually, of course, these jumps would be of progressively smaller amplitude, decreasing to zero as the short circuit transient dies out.

It is interesting to compare the stress thus created in the bolts with that required, as initial tension, to prevent any motion.

The force on the bolts at $x = 0$ is, by (28) and the data,

$$f_0 = 1.5\,K\,I_o^2 - W = 10\,W - W = 9\,W = 9000 \text{ lb.}$$

By equation (3) the total force on the bolts is

$$f_s = -(f_o + k\,x)$$

$$k = 144 \times 10^6$$
$$x = 106 \times 10^{-6} \text{ ft.}$$

Thus

$$f_s = -(9000 + 144 \times 10^6 \times 106 \times 10^{-6}) = -24{,}300 \text{ lb.}$$

That is, the maximum force on the bolts is 24,300 lb.

The peak force is by (7)

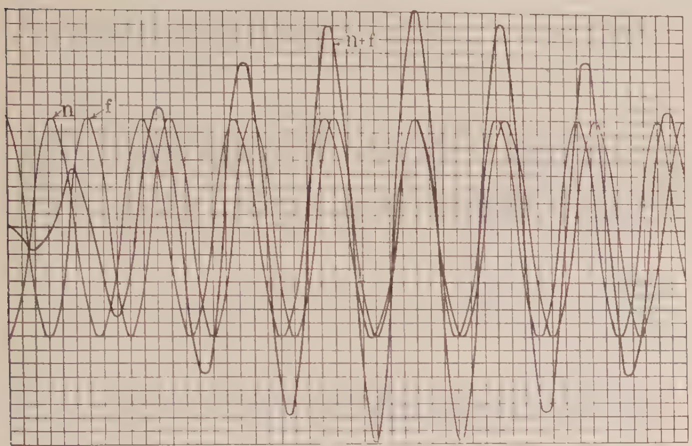

FIG. 5

$$f_m = 4\, K\, I_o^2$$

But, in the particular problem, by assumption

$$K I_o^2 = 6.66\, W = 6660 \text{ lb.}$$

Thus

$$f_m = 4 \times 6660 = 26{,}640 \text{ lb.}$$

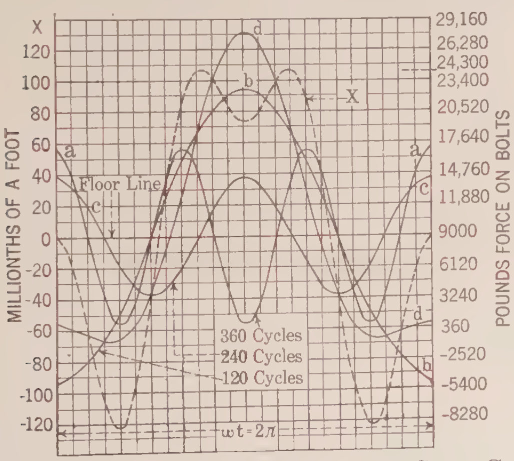

FIG. 6—CASE 3. HYPOTHETICAL CASE. SAME CONDITIONS AS IN CASE 1, EXCEPT THAT THE ELECTRICAL FREQUENCY IS ASSUMED TO BE DOUBLED

$x = 10^{-6}$ (56.2 cos 2260 t − 93.7 cos 754 t + 37.5 cos 1508 t)

a = 1st term, b = 2nd term, c = 3rd term, $d = b + c$, $x = a + b + c$

$4k\ I_0^2$ = 26,640 lb.

Thus the maximum force on the bolts is slightly less than the maximum magnetic force.

CASE 3

To study the effect of electrical frequency, assume all other data as in *Case* 1 except the electrical frequency, taking the latter as double, that is,

$$f = 120 \text{ cycles.}$$

Applying equation (**29**),

$$x = 2\frac{6660}{31 \times 754^2}\left[\left\{-\frac{1}{1-(360/120)^2} + \frac{0.0625}{1-(360/240)^2}\right\}\cos 2260\, t + \left\{\frac{\cos \omega\, t}{1-(360/120)^2} - \frac{0.0625 \cos 2\, \omega\, t}{1-(360/240)^2}\right\}\right]$$

Thus $x = (56.2 \cos 2260\, t - 93.7 \cos 754\, t + 37.5 \cos 1508\, t)\, 10^{-6}$

This is plotted in Fig. 6. It will be observed that the amplitudes of the different waves are of about the same magnitude as those in *Case* 1, but the phase relation of the different frequencies gives a different shape of resultant wave x. Thus the maximum value of x is approximately 170×10^{-6} feet in *Case* 1, and -120×10^{-6} in *Case* 3. These correspond respectively to 33,480 lb. and 8300 lb. on the bolts. In *Case* 3, if the positive peak of 106×10^{-6} in Fig. 6 is taken instead of -120×10^{-6}, the force on the bolts would be 24,300 lb. instead of 8300 lb. Thus the result of doubling the electrical frequency and keeping all other factors the same as in *Case* 1, is a decrease in the peak force on the bolts from 33,480 lb. to 24,300 lb.

CASE 4

Find the effect of the floor, other conditions being the same as in *Case* 3. Following the same procedure as in *Case* 2, new integration constants C_1 and C_2 are

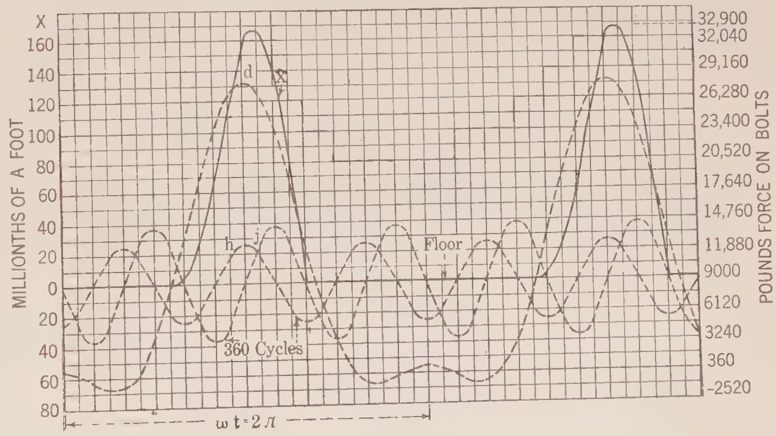

FIG. 7—CASE 4. CURVE SIMILAR TO FIG. 4, CASE 2

All conditions being of the same except the electrical frequency is assumed to be doubled.

$x = 10^{-6}$ (− 24.3 cos 2260 t − 35.9 sin 2260 t − 93.7 cos 754 t + 37.5 cos 1508 t)

$x = d + h + j$ for values of d > zero. d = same as in Fig. 6

$4\ k\ I_0^2$ = 26,640 lb.

determined from the conditions that, at

$$\omega\, t = 103°$$
$$x = 0$$
$$\frac{d\,x}{d\,t} = 0$$

That is, the reactor begins to leave the floor at the moment when the magnetic force becomes equal to $(f_0 + W)$ which occurs at $\omega t = 103°$.

The forced oscillations, *i. e.* the ωt and $2\omega t$ terms, will be the same as in *Case* 3. Thus:

$$x = (C_1 \cos 2260\,t + C_2 \sin 2260\,t - 93.7 \cos 754\,t + 37.5 \cos 1508\,t)\,10^{-6} = 0$$

and
$$\frac{d\,x}{d\,t} = (-\,2260\,C_1 \sin 2260\,t + 2260\,C_2 \cos 2260\,t + 70{,}650 \sin 754\,t - 56{,}600 \sin 1508\,t)\,10^{-6} = 0$$

Therefore

$$C_1 = -\,24.3$$
$$C_2 = -\,35.9$$

and
$$x = (-\,24.3 \cos 2260\,t - 35.9 \sin 2260\,t - 93.7 \cos 754\,t + 37.5 \cos 1508\,t)\,10^{-6}$$

This is plotted in Fig. 7. The maximum deflection is $x = 166 \times 10^{-6}$ feet, which corresponds to a force on the bolts of 32,900 lbs. The peak magnetic force is, as before, 26,640 lb. It is very interesting to compare *Cases* 1 and 2 with *Cases* 3 and 4, the conditions in the latter two cases being the same as in the former two except that the electrical frequency is doubled. In *Case* 2, the effect of interposing the floor was to decrease the maximum deflection below that in *Case* 1, where the reactor was free to oscillate. In *Case* 4, however, the effect of the floor is to *increase* the deflection above that in *Case* 3, where the reactor was free to oscillate. Moreover, although the maximum deflection in *Case* 3 (free oscillation) was less than that in *Case* 1 (free oscillation), nevertheless it was more in *Case* 4 than in *Case* 2.

Case 5

Take the case where the reactors are *rigidly* bolted to and supported by I-beams, assuming one reactor mounted vertically above the other. Assume also that the resilience factor[11] k is the same as that used in *Case* 1, namely,

$$k = 144 \times 10^6 \text{ lb./ft.}$$

In this case f_0 is zero. Also at $t = 0$, the steady deflection x_1 is that which is caused by the weight W. Thus taking upward motion as positive

$$k\,x_1 = -\,W$$

and

$$x_1 = -\,W/k$$

Thus equation (**26**), modified for these boundary conditions, becomes

$$x = \left[2\frac{K I_o^2}{M\omega^2}\left\{-\frac{1}{1-(n/f)^2} + \frac{0.0625}{1-\left(\frac{n}{2f}\right)^2}\right\} - 1.5\frac{K I_o^2}{k}\right]\cos \alpha t$$

$$+\,2\frac{K I_o^2}{M\omega^2}\left\{\frac{\cos \omega t}{1-(n/f)^2} - \frac{0.0625 \cos 2\,\omega t}{1-\left(\frac{n}{2f}\right)^2}\right\} + \frac{1.5\,K I_o^2 - W}{k} \qquad (\mathbf{30})$$

Substituting,

$K I_o^2 = 6660$ $M = 31.0$ $\omega = 377$ $f = 60$

$n = 360$ $\alpha = 2260$ $W = 1000$ $k = 144 \times 10^6$

$$x = (-\,6.48 \cos 2260\,t - 86.45 \cos 377\,t + 23.6 \cos 754\,t + 62.4)\,10^{-6}$$

This is plotted in Fig. 8. The maximum deflection is 166.5×10^{-6} feet, which corresponds to a force on the I-beam supports of

$$144 \times 10^6 \times 166.5 \times 10^{-6} = 24{,}000 \text{ lb.}$$

The peak or maximum magnetic force is, by assumption, 26,640 lb.

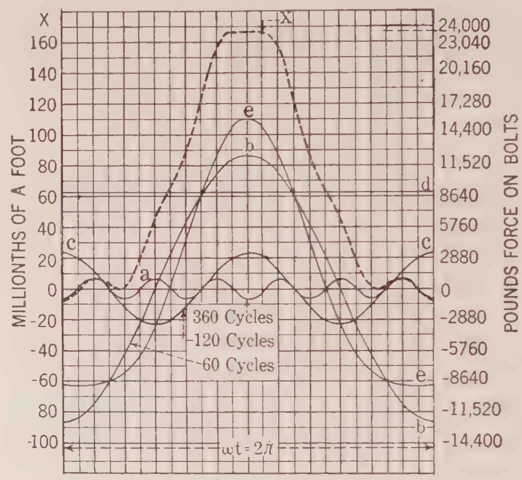

FIG. 8—CASE 5. REACTORS RIGIDLY BOLTED TO I-BEAM SUPPORTS INSTEAD OF RIGID FLOOR

Center lines of reactors in same vertical line, similar to Fig. 1. Resilience constant of *I*-Beam support same as for bolts in Case 1 (*i. e.* $k = 144 \times 10^6$)

$x = 10^{-6}(-\,6.48 \cos 2260\,t - 86.45 \cos 377\,t + 23.6 \cos 754\,t + 62.4)$

a = 1st term, b = 2nd term, c = 3rd term, d = 4th term, $e = b + c$

$x = a + b + c + d$

$4\,k\,I_0^2 = 26.640$ lb.

The foregoing examples cover special cases of single-phase short circuit, with off-set current wave, and sine wave a-c. component, and with physical arrangement as shown in Fig. 1. For the case of reactors placed side by side, similar equations would apply, the main difference being that moments, instead of forces, would be involved provided the reactors were held by holding bolts in the floor, and no horizontal braces between them.

The case of three-phase remains. In this, as in the foregoing cases, the various factors enter in the same way, the difference being only in the character of the magnetic force. But whatever may be its character, it may be expressed as a function of time, and treated

11. Ratio of force exerted on the I-beam support to deflection it produces.

as in the case of single-phase. Thus the magnetic force on one of three reactors would be

$$f_{c1} = K_{12}\, i_1\, i_2 + K_{13}\, i_1\, i_3 \tag{31}$$

where K_{12} and K_{13} are constants.

The instantaneous values of short-circuit currents i_1, i_2 and i_3 in the three phases can all be expressed as functions of time, and these expressions substituted in the differential equation (4). Thus the problem involves longer equations with more terms, but they are of exactly the same character, and solved in the same way.

Discussion of Results

The value of the results from a mathematical treatment of this sort depends upon how sound and comprehensive the assumptions are on which the equations are based. These are given at the beginning of the paper. The most questionable assumptions perhaps are that the supporting floors are rigid and that the entire structure of the reactor unit, is a rigid body. There will naturally be some slight deformation of the structure under such great stresses.

In *Cases* 2 and 4, Figs. 4 and 7 respectively, in which the reactor is shown to take successive "jumps" from the floor, the curves show return to the floor without rebound or bouncing. Such bouncing of course would actually occur. That is, the curve would be more accurate if it showed a decaying series of initially small rebounds, following the return to the floor, as now shown on the curve.

Damping is neglected. This assumption makes negligible difference excepting cases of near resonance as discussed later.

The peak magnetic force depends upon the point of the voltage wave at which the short circuit occurs. But the assumption that it occurs at the zero voltage point, resulting in a completely off-set wave, gives the greatest possible peak value of magnetic force.

The examples in *Cases* 2 and 4 assume initial tension on the holding bolts equal to $(1.5\, K\, I_o^2 - W)$. With zero initial tension, and $1.5\, K\, I_o^2 > W$, then motion would obviously be an oscillation above the floor, and about an average deflection equal to the strain of the bolts produced by the force,

$$1.5\, K\, I_o^2 - W$$

It is very important to observe that in the equation for deflection, for instance equation (26), the motion x of the reactor is a function of the ratio n/f. Consider what this means. The factor

$$2\,\frac{K\, I_o^2}{M\, \omega^2}$$

in equation (26) is the amplitude of the oscillation which would be produced in the mass M by the alternating force,[12]

$$2\, K\, I_o^2 \cos \omega\, t$$

provided the mass were disconnected from resilient supports—*i. e.* if, say, it were suspended as a pendulum, and this alternating force were applied in horizontal line, then

$$2\,\frac{K\, I_o^2}{M\, \omega^2}$$

would be the amplitude of oscillation in the horizontal line.

Now if one end of a resilient, or spring-like, horizontal support is attached to the mass, and the other end fixed, and the same alternating force applied, the amplitude of oscillation will be changed by the factor

$$\frac{1}{1 - (n/f)^2}$$

It would thus be

$$2\,\frac{K\, I_o^2}{M\, \omega^2} \cdot \frac{\cos \omega\, t}{1 - (n/f)^2}$$

This will be recognized as the term of fundamental frequency in equation (26).

Similarly, the second harmonic term in equation (26) is

$$0.5\,\frac{K\, I_o^2}{M\, (2\, \omega)^2}\;\frac{\cos 2\, \omega\, t}{1 - \left(\dfrac{n}{2\, f}\right)^2}$$

the magnitude of the 2nd harmonic force[13] being one-quarter of that of the fundamental.

For illustration consider the fundamental term. If

$$n/f > \sqrt{2}$$

then obviously the amplitude of oscillation will be less than

$$2\,\frac{K\, I_o^2}{M\, \omega^2}$$

if, however,

$$\frac{n}{f} < \sqrt{2}$$

the amplitude will be greater[14] than

$$2\,\frac{K\, I_o^2}{M\, \omega^2}$$

the values of amplitude for ratios between $\sqrt{2}$ and zero falling along the characteristic resonance curve, reaching infinity at ratio equal to unity, then decreasing again, approaching

$$2\,\frac{K\, I_o^2}{M\, \omega^2}$$

for low values of ratio.

The mass M thus enters in two ways. First as inertial resistance to motion produced by the impressed force as shown by the factor

$$2\,\frac{K\, I_o^2}{M\, \omega^2}$$

and, second, as inertial resistance to motion produced by the force of the strained resilient support. Its effect here is accounted for in the factor n; since by equation (25)

$$n = \frac{1}{2\, \pi}\, \sqrt{k/M}$$

12. This is the fundamental term in equation (7).

13. As given by equation (7).

14. If $n = 2\, f$, this would, of course, be resonance for the $2\, \omega\, t$ term. These particular numerical values for the fundamental term alone are given merely for illustration of how the frequency ratio affects an oscillation.

Thus the deflection is dependent upon the ratio n/f as well as the mass M, and it does not necessarily follow that, with the same impressed force, increasing the mass will decrease the amplitude, because the change in the frequency ratio might be such as to increase the amplitude.

To illustrate: if

$$n/f < 1.0$$

increasing the mass will decrease the amplitude,[15] whereas if, for instance,

$$n/f = 2.0$$

then doubling the mass would obviously decrease the factor

$$2 \frac{K I_o^2}{M \omega^2}$$

by 50 per cent, but it would increase the factor

$$\frac{1}{1 - (n/f)^2}$$

from 0.333 to 1.0. Thus the net result would be an *increase* from 1.0 to 1.5, that is, a 50 per cent increase.

However, the full significance of the dependence of the amplitude upon the frequency ratio is not clear without consideration of the effect of the transients. There are two of them, namely, the transient of the short-circuit current, with consequent decrease in the magnetic force; and the transient of the free oscillation due to friction or damping. Both are neglected in the equations. The justification for this is two-fold: the natural frequency n as explained later, is usually enough greater than f to give the peak deflection in the first cycle of the electrical frequency, as in the *Cases* 1 to 5 inclusive, in which, neither transient, if they had been included in the equation, would have changed the oscillations significantly. Also, even if significant transients do exist, the calculated result is on the safe side, giving calculations slightly too high.

As resonance is approached, however, the transients are very important. For instance, by equation (**26**)[16] it is evident that if $n = 0.9 f$, the amplitude of the ωt term will be approximately

$$10 \frac{K I_o^2}{M \omega^2}$$

while that of the $2 \omega t$ term will be only

$$0.156 \frac{K I_o^2}{M \omega^2}$$

thus, practically negligible. But while the ωt term is large, so is the αt term equally large and opposite. Hence, as shown in Fig. 5, the two waves, starting out in phase opposition, give practically zero resultant at first, which gradually builds up by successive phase shift due to slightly different frequencies, until ultimately, at 4.5 cycles of n and 5 cycles of f, the waves add in phase, giving a maximum equal to twice the amplitude of either wave. Then, for the same reason, it decreases again.

All this, provided there are no transients. But of course, there are transients. If the electrical damping were zero, then the free oscillation alone would die out due to mechanical damping, leaving only the forced oscillation, *i. e.* the ωt and $2 \omega t$ terms. Thus, as the former dies out, it leaves the latter, which it initially opposed and canceled. Hence if the transient of the free oscillation were rapid enough, the resultant oscillation would reach a maximum earlier than if that transient did not exist, but the maximum would be only half as great—namely, the forced oscillation alone. While there are very few data on the mechanical damping, it is probable that both transients—that is, the mechanical transient and the transient of the ωt term—are of about equal duration, say one-quarter second. In such a case, the maximum deflection would be the result of a race between the increase in magnitude due to phase shift of waves of different frequencies, on the one hand, and to a decrease due to transients, on the other. It is clear, therefore, that at near resonance the transient cannot be neglected.

To illustrate in a very rough quantitative way the effect of transients at near resonance, take *Case* 5, *I*-beam supports, assuming,

$n = 0.9 f$
$f = 60$ cycles
neglect $2 \omega t$ term
neglect W
duration of transient of ωt term same as of mechanical transient = 1/4 second.
transients of form $\epsilon^{-\gamma t}$

By assumption[17] $\gamma \simeq 20$

Applying equation (**30**)

$$x \simeq \epsilon^{-20t} \left[- \left\{ \frac{10 K I_o^2}{M \omega^2} + 1.5 \frac{K I_o^2}{k} \right\} \cos \alpha t + \frac{10 K I_o^2}{M \omega^2} \cos \omega t + 1.5 \frac{K I_o^2}{k} \right]$$

Since $n = 0.9 f$

$\alpha = 0.9 \omega = \sqrt{k/M}$

Hence $M \omega^2 \simeq 1.25 k$

and
$$x \simeq \epsilon^{-20t} \left[- \left\{ \frac{8 K I_o^2}{k} + \frac{1.5 K I_o^2}{k} \right\} \cos \alpha t + \frac{8 K I_o^2}{k} \cos \omega t + \frac{1.5 K I_o^2}{k} \right]$$

Or $x \simeq \epsilon^{-20t} \dfrac{K I_o^2}{k} [- 9.5 \cos \alpha t + 8 \cos \omega t + 1.5]$

15. Because an increase in M decreases both of the factors $2 \dfrac{K I_o^2}{M \omega^2}$ and $\dfrac{1}{1 - (n/f)^2}$, the latter being decreased since $n = \dfrac{1}{2 \pi} \sqrt{K/M}$.

16. Remembering that the amplitude of the free oscillation is just equal and opposite to the amplitude of the forced oscillation at t = zero. And hence if the frequencies are about equal, it will take considerable time for the two waves to gradually shift out of phase, thus building up the resultant wave. At resonance it would theoretically take an infinite time.

17. The transient term is assumed to apply to all terms in the equation. Strictly it applies to the αt and ωt terms, and to only a component of the constant term. But since the latter is small, the assumption, for purpose of illustration, is justified.

This is plotted in Fig. 9. The maximum value of x occurs at about two cycles, and is

$$x_m = 6.5 \frac{K I_o^2}{k}$$

This corresponds, by equation (3), to a force on the support

$$f_s = k\, x_m = 6.5\, K\, I_o^2$$

That is, about 60 per cent greater than

$$4\, K\, I_o^2$$

which, by equation (7), is the maximum instantaneous magnetic force neglecting the transient.

If n is large compared to f the shape of the resultant deflection wave is that produced by the superposition of a high-frequency wave on one of lower frequency as shown in Fig. 3. Thus, the high-frequency wave a superposed on the lower frequency wave d produces the resultant curve x. If the ratio of the high-frequency n to the low-frequency f is an integer then the resultant wave repeats every cycle of the frequency f and therefore the maximum will occur in the first cycle of $\omega\, t$. If the ratio is not an integer the resultant will not repeat and will, without transients, require a few cycles of f for the relative phase of the high-frequency wave to shift to the right position to give the maximum possible resultant. However, transients probably reduce the magnitude more rapidly than the phase shift builds it up. It thus appears reasonable to assume in this case also that the maximum occurs in the first cycle of $\omega\, t$.

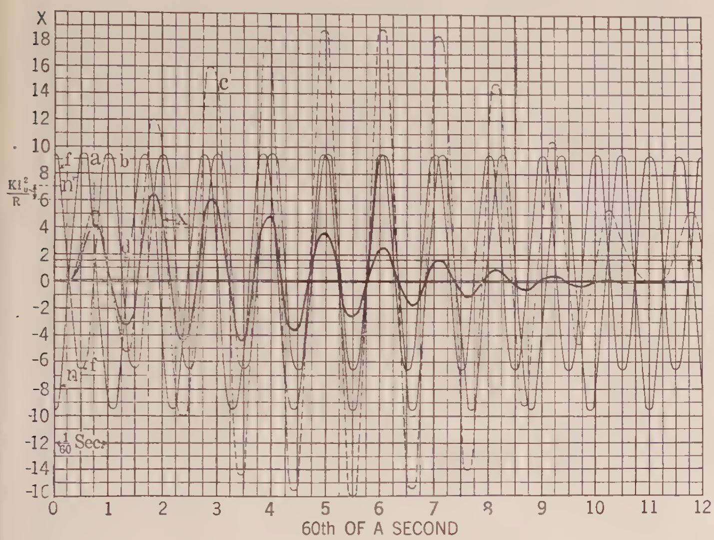

FIG. 9

$x = E^{-20t}\ k\, I_0^2/k\ [\, k\, 9.5 \cos \alpha\, t + 8 \cos \omega\ t + 1.5\,]$

a = 1st term, b = 2nd term, $c = a + b$, d = 3rd term

From the foregoing discussion of results, it appears that in cases where n is large compared to f the results are accurate enough to certainly indicate the general character of the phenomenon and magnitudes involved, and probably also close enough for guide in design calculations. In such cases, neglecting the transients would not involve serious error. However, it is clear from the numerical illustration just given, that where n approaches f, the transients can not be neglected. That is, the equations do not apply in such cases. But usually in problems of actual practise n is large compared with f.

CONCLUSIONS

(1) If the reactor is not held rigidly against all motion, the maximum force on the holding device (bolts, etc.) will depend in a decisive way upon the ratio of the frequency n of natural oscillation, to the electrical frequency f.

(2) If, however, the reactor is held rigidly, then the maximum force on the holding device will be independent of the frequency ratios, and need be only slightly in excess of the peak magnetic force. Or, conversely, if the initial tension in the holding device (plus weight of reactor) is equal to, or slightly greater than, the peak magnetic force, then no motion of the reactor can take place. It appears that this condition should always be sought.

(3) If the reactors is not held rigidly and n is large compared to f, say

$$n/f > 3$$

as is usually the case, then if motion is permitted, the maximum force on the holding device will occur in the first cycle of $\omega\, t$, and will usually be as great or greater than the maximum magnetic force.

(4) If $n/f < 3$ and the reactor is not held rigidly, the maximum deflection may or may not occur in the first cycle of $\omega\, t$. If it does, then the above conclusion applies. If it does not, then the transient cannot be neglected, and the equations do not apply. It is probable however, that in the latter, as in the former case, the maximum force on the holding device will be greater, than the maximum instantaneous magnetic force.

(5) The equations, which are based on definite assumptions given at the beginning of the paper, and discussed in foregoing pages, give results which indicate the general character of the phenomenon and magnitudes involved; and within limits specified,[18] could probably be used as a guide in design calculations.

The authors wish to acknowledge the valuable suggestions of Mr. W. O. Dwyer and the assistance of Messrs. D. S. Snell and R. F. Franklin.

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18. Cases where $n > 3f$.

Discussion at Midwinter Convention

APPARENT DIELECTRIC STRENGTH OF CABLES* (WISEMAN). NEW YORK, N. Y., FEBRUARY 14, 1923

John B. Whitehead: If I understand Mr. Wiseman aright, he has found an agreement between the results of observation on the dielectric strength of cables and the application of certain empirical laws, based on the behavior of gases. As regards ionization, his suggestion is that it may be possible to explain the laws of cable failures in terms of ionization of the dielectric.

It seems to me there are two reasons why we must go slowly here. The first is that the results of observation on the behavior of dielectrics in cables are not consistent. We are not yet able to bring the various people working in this field together, and as we hear succeeding papers, we find differences in points of view, and differences in results.

The second reason, why we must go slowly, is because there is no evidence of a free mobility of ions in solid dielectrics, as recognized by the author. In the case of gases we find consistent laws, and various experimenters agree; we have a satisfactory explanation in ionization by collision, of the breakdown of gases. But even though we have these empirical laws, and an elaborate theory explaining the phenomena, we still are not in a position to say just what is going on in a gas when it breaks down.

As you know, we have a definite law for stating the critical gradient at which air breaks down, in terms of the shape of the dielectric, but that is a far cry from saying what is going on in the molecule of gas, when it lets go. The law connecting the diameter of the conductor with the breakdown strength of air, while simple on paper, nevertheless does not tell us what is going on in the molecule.

R. W. Atkinson: The author has shown what seems an interesting mathematical expression for the data of the various groups analyzed. However, I do not believe that there is justification for the physical intrepretation which is made nor even for the giving of the equation for K on page 166 as expressing an empirical law covering the data analyzed.

There is reason to suppose that a formula similar to that applying for corona in air may apply in many cases to solid or semi-solid insulators. As a whole however the data quoted by the author tends as much to disprove as to prove this theory. There is very little foundation in the data presented for the introduction of the new term in the formula.

E. W. Davis: We quite agree with Mr. Wiseman that if the voltage rupturing of dielectrics on cables is carefully analyzed from all angles, we may finally arrive at a complete understanding of what voltage breakdown actually is. We would like, however, to emphasize the fact that because of the erratic nature of breakdown tests, many more actual tests must be made before such a complete understanding can be arrived at. By analyzing the few sets of data available today, we hardly produce conclusive deductions. An example of this is found in the data published by Mr. Fernie. Further tests made by him quite upset the theory that he at first advocated.

The so-called Middleton formula ($K = 5.44\ V/D$) was only proposed by its authors as applying to cables whose ratio R/r is greater than 2.72. For cables whose ratio is less than 2.72, the simple theoretical formula ($K = 0.434\ V/r \log_{10} R/r$) has been found to apply.

Comparing the values of K (or maximum stress) as computed by Mr. Wiseman's formula with the values computed by the Middleton formula, as shown in Tables I to IV, we find that by the latter formula, the values generally show fewer deviations from the averages and that the averages for the cables whose ratios R/p are greater than 2.72, check more closely with the actual stresses for cables whose ratio are less than 2.72. This is shown in the following table.

Table	Average K for $R/r > 2.72$ Wiseman	Middleton	Max. Deviations from Average Wiseman	Middleton	Actual K for R/r < 2.72
I	347	324	21%	18.8%	226
II	197	197	10.7	15.9	168
III	668	480	30.0	18.3	512
IV	774	527	60.2	12.9	346
V	920	609			
VI	224	206	2.22	4.85	215

It should be noted that for Tables III, IV and V, the results obtained by the Middleton formula are much more consistent than those obtained by the formula proposed by Mr. Wiseman, while in Tables I, II and VI there is little choice between the two formulas.

G. B. Shanklin: Mr. Wiseman's paper is the third vital paper on dielectric strength presented before the Institute in the past few months. Our knowledge of dielectric strength is thereby vastly increased.

The first by Mr. Middleton, presented at Niagara Falls Convention, indicated that the dielectric strength of cables should be expressed by empirical formulas and not by a maximum, minimum or average stress theory. In the discussion which followed Mr. Middleton's paper an illuminating ray of light was thrown on the problem by the words of Dr. Steinmetz, Mr. Peaslee and Mr. Peek. Their discussions predicted and guided the trend of the investigation in a truly remarkable way.

Afterwards, Dr. Wagner presented a paper at Chicago on the "Electrical Breakdown of Solid Dielectrics," ascribing breakdown to a true accumulative conduction, concentrated in small, weakened spots of the insulation thickness. His work is in such good agreement with the beliefs of Dr. Steinmetz, Mr. Peaslee and others, and is, in itself, so convincing that it is sure to have a decided bearing on future work. Dr. Wagner dealt only with parallel dielectric fields and did not apply his theory to the more complicated fields met with in cable cross sections.

The present paper by Mr. Wiseman is an elaboration of the empirical corona formula suggested by Mr. Peek and shows without any question of doubt, that the law of breakdown in cables must be expressed empirically. It appears to me, however, as misleading to attempt to explain this as due to some form of ionization, such as corona in air. It is hard to see how there could be ionization of this nature in solid material. The mean free path of electrons is entirely too small. That an almost similar "energy distance" formula will express the law of breakdown in cables does not necessarily mean that the phenomena are similar. Rather, it means that the shape of the dielectric field is involved in both cases. The shape of the dielectric field determines the distribution of voltage gradient, so perhaps it is more accurate to say that the voltage gradient is involved in both cases.

In the discussion previously referred to, both Dr. Steinmetz and Mr. Peaslee indirectly show how Mr. Wiseman's empirical results can be explained by Dr. Wagner's conduction breakdown theory. The density of the conduction current, which is determined by the voltage gradient, must reach a critical value some distance out from the conductor before actual breakdown occurs. In the case of corona in air, the voltage gradient determines the velocity of the ions and therefore the required critical distance for ionization by collision. The two cases are similar only in the above respects, but it so happens that this is sufficient to give them the same form of mathematical expression.

*A. I. E. E. JOURNAL, 1923, Vol. XLII, February, p. 165.

W. N. Eddy: Although Mr. Wiseman's detailed analysis of the available breakdown data on cables is very interesting and valuable, it leaves the impression that in studying the breakdown of cable insulation he considered only the voltage impressed on the insulation, the thickness of the insulation and the dimensions of the electrodes. No reference to either the temperature of the cable or the time of application of the voltage could be found in the paper. Such a point of view, if true, gives a misleading idea of the problem and while a formula developed from such data may represent the test data satisfactorily it will not give an adequate idea of the behavior of the cable in service at constant voltage and varying temperatures. In this connection it is interesting to note the statement made by Dr. Steinmetz in a recent discussion.*

"An extensive investigation of this problem of the mechanism of breakdown of solid insulation has been carried out during the last few years in my laboratory by Mr. Hayden and his assistants in which we derived the conclusion, or rather were forced to the conclusion, that there exists no such thing as a definite breakdown voltage or breakdown gradient of solid insulation."

It seems to be well established that the breakdown of insulations is caused by local overheating. This in turn may be caused by unhomogeneity of the insulation, by overloading and therefore overheating of the cable at normal voltage, by the application for a short time of voltage greatly in excess of normal or by the application for a longer time of voltage slightly in excess of normal. For instance, a cable in service is under practically constant voltage throughout its life. After more or less time the various temperature cycles finally cause a point in the insulation to develop that begins to take a little more current than the other points, this increase of current results in more local heating which in turn means more current and so on until the insulation carbonizes and breakdown results.

For such reasons it would seem reasonable that any investigation on the dielectric strength of cables should devote as much or more attention to the effect of temperature and time than to that of the voltage alone.

Wm. A. Del Mar: The various attempts of Jona, Middleton, Atkinson, Peek and Wiseman to find some constant value of the electric stress which will determine the breakdown voltage of cables have been only partially successful because it is not yet possible to make a number of samples of cable of identical dimensions which will breakdown at the same voltage. Indeed, apparently identical flat samples of impregnated paper show a variation of at least 10 per cent above and below the average in breakdown voltage.

It therefore seems hopeless to expect electrical uniformity of material in samples of different dimensions in an attempt to find a law connecting breakdown voltage and dimensions.

Whereas leakage of current depends upon average conditions, breakdown voltage depends upon maxima and minima. It is probable that a solid or semi-solid dielectric would never breakdown under stress if it were absolutely homogeneous. Increasing the potential gradient would simply increase the leakage and nothing would happen unless the heat generated were confined. Failure results from some local facility afforded to ionic flow. In the case of impregnated paper this may be a spot where the paper has low baffling effect to ionic motion, or a portion of the oil rich in free ions or a vapor pocket where vapor ionizes and sets up local surges.

The only way to overcome the difficulties due to the inherent heterogeneity of dielectrics, is to test a very large number of samples. The deductions of Middleton, Atkinson, Peek and Wiseman, have been drawn from too limited a number of tests. Such tests are very expensive and seriously tax laboratory facilities in the factories. It seems as if cooperative research would be necessary to reach a solution of this problem.

In the meanwhile some statistical data are obtainable from factory records extending over long periods. Thus during six consecutive months of 1922, the records of one company show that the breakdown voltage of sector cables runs about 100 kv. for each centimeter of insulation thickness between conductors. Occasionally this figure would run up to 125 or down to 75, but the general run was unmistakably represented by 100 kv. per cm.

During the same period, two sizes of high-voltage single-conductor cables were made and numerous samples tested. Their dielectric strength as derived from Peek's formula was found to be about 100 kv. per cm. with occasional samples running above and below to about the extent mentioned for sector cables.

The dielectric strength of impregnated paper should be of this order because that of petrolatum is about 30 kv. per cm. by Peek's formula, and the multiplying effect of the paper is found experimentally to be of the order of 3.

Mr. Wiseman's experiments appear to have been made on ceresine and not on impregnated paper. These two materials exhibit totally dissimilar characteristics under stress and I am inclined to give very little weight to any formula derived from tests on the former, when applied to the latter. Possibly the free ions in ceresine are not determining factors, but C. F. Hanson and I, in an Institute paper last year, gave experimental evidences of the existence of free ions in petrolatum and since we have obtained additional experimental evidence of ionic stimulation in impregnated paper under electric stress and have developed a practical measure of the baffling effect of paper to ionic motion. Whether true or false, this theory has been of great practical use in cable making, as it has enabled the dielectric strength to be varied over a range from 50 to 150 kv. per cm., at will. All of this is inconsistent with the idea that impregnated paper obeys a law based upon tests on a solid dielectric, such as ceresine.

The formula developed by Mr. Wiseman may, of course, prove to be of great value in the case of solid insulation.

R. J. Wiseman: The writer agrees with Dr. Whitehead that we should go slowly in applying the empirical laws for ionization of gases to solids. We know very little about ionization in solid dielectrics. I started with the assumption there may be something in it and was surprised to obtain what I consider sufficient agreement to warrant further investigation. It is a problem for the physicist and I hope someone else will take up the study and give it a thorough analysis, either to prove or disprove what has been advanced. It must not be laid aside just because there are no visible or physical effects present on account of ionization. The writer does not believe such effects need to be a necessary adjunct to ionization. We can have ionization in gases without any visible or physical effects, why is it not possible in solids?

It would have been a great help to us if Mr. Atkinson had shown why he believes the data quoted in the paper tends as much to disprove as to prove the theory advanced. The data given in five of the six tables were obtained from papers presented at the Niagara Falls Convention. Considering the different sources of data and the fact that the new empirical formula gave better agreement than other formulas seems to tend more to prove the theory rather than to disprove it.

The formula presented states that the dielectric strength is a function of the radii of conductor and insulation as well as their ratio. Consequently we cannot average up the values of K in the theoretical formula for dielectric strength if the radius of conductor varies as has been the case in the tables given in the paper. Bearing this in mind, the table Mr. Davis presents has no weight. Take Table IV of the paper which is a copy of Table II of the Middleton, Dawes and Davis paper, we have a range of K by the theoretical formula from 1355 volts per mil to 326 volts per mil, K decreasing as the radius of the conductor increases. It is obvious we have no right to average such a wide range in K.

Mr. Eddy's remarks pertaining to no reference to either temperature of the cable or the time of application of the voltage bring out a serious offense against what we should do when pre-

*A. I. E. E. JOURNAL, December, 1922.

senting data and the writer apologizes for not including this information in the paper. The tests given in Table VI from the writer's previous work were made at room temperature and an increase of voltage of about 1000 volts per second. We all admit that very long time constant voltage tests when the voltage is near the rupturing voltage and varying temperatures give different results than short time voltage tests and constant temperature.

The writer is unable to appreciate Mr. Del Mar's remark that "it is probable that a solid or semi-solid dielectric would never breakdown under stress if it were absolutely homogeneous." The writer agrees with Mr. Del Mar that it is necessary to conduct many tests before we can feel we have solved the problem in question. However it is necessary to make a start at drawing conclusions after a reasonable number of tests have been made. The data presented by Messrs. Middleton, Dawes and Davis are the results of many tests at each point and the data given by the writer in Table VI are the result of at least 10 tests at each point. The average deviation for each point was low and therefore the average value could be accepted as representing as well as experimental work was possible, the phenomenon taking place for the conditions under test.

Considering the agreement which the new formula gives between computed and actual values of K for each of the tables given in the paper and the fact that all but five of the tables were taken from papers by authors and on different dielectrics gives the formula more weight and that there may be something more worth while in it than Mr. Del Mar seems to believe. Very true, ceresine and impregnated paper exhibit totally dissimilar characteristics and this is brought out in the expression $K = K_0 (1 + a/\sqrt{r}\sqrt{R})$. The dissimilarity would be shown in the value for a, K and whether a positive or negative sign would occur. The baffling effect referred to by Mr. Del Mar is due to the higher amount of free ions and the greater freedom of mobility of ions in petrolatum than in paper. Change the freedom of mobility in paper and you will change the characteristics of impregnated paper.

I am very glad Mr. Del Mar reports evidence of free ions in petrolatum. It helps to substantiate what the writer has believed for many years. The writer views the problem as to what is a dielectric, as follows, all substances, gases, liquids, and solids have free ions, different substances having different amounts and each substance having a different mobility, both of which determine the dielectric strength of the substance. The number of free ions in gases is large and freedom of motion great, therefore we get low dielectric strength. Liquids may be classed as the next higher order of dielectric, having less free ions and less mobility than gases. Solids present the case of where free ions are few and freedom of motion greatly limited, resulting in high dielectric strength. The above refers to homogeneous materials. Where we have a non-homogeneous substance such as rubber each of the pure substances in the rubber has its own influence on the resulting material. For a substance like impregnated paper in a cable we have the combination of liquid, and paper impregnated with a liquid. The liquid alone has a property of its own but the impregnated paper is a combination of liquid and the solid paper. The resulting material may have any number of characteristics as the liquid and paper alone and in combination vary. It may even happen that for the same liquid and paper, two cables may exhibit different properties on account of some slight change in the treatment or manufacture which would change the ionic characteristics of each dielectric.

The writer appreciates greatly the remarks of Mr. Shanklin in referring to the views of Dr. Steinmetz, Dr. Wagner and Messrs. Peaslee and Peek. The writer's paper was written in August, 1922 prior to the publication of Dr. Wagner's paper and the discussion of the papers presented at the Niagara Falls Convention.

Without being too bold, since reading Dr. Wagner's paper and the remarks of Mr. Peaslee the question has arisen in the mind of the writer, are we all referring to the same thing? Is Dr. Wagner's conduction breakdown theory and Mr. Peaslee's ideas the same as the views expressed by the writer but expressed differently. They view the subject from a changing conduction angle whereas the writer looks upon it as an ionization phenomenon. Corona such as we call the visible glow in air when the ionization becomes great enough to make the air conducting is not necessary before we say ionization takes place. Mr. Bergen Davis[1] in a paper presented before the Institute in 1914 showed that ionization and corona are practically identical. Some of his ideas present a good foundation for a study of the phenomenon of ionization. Ionization in gases takes place as soon as the voltage stress is great enough to cause the free ions to move and create other ions by impact. It seems reasonable to suppose that the same will be true for the free ions in a solid. Furthermore it is not necessary that there be any physical effects resulting from the formation of ions in the dielectric. If we agree to these statements, then it is not so difficult to explain some of the phenomena of the electrical breakdown of dielectrics. Taking Mr. Peaslee's discussion of the papers presented at the Niagara Convention. Is the current he refers to partly the current due to ionization and not entirely a conduction current obtained from resistance? As the voltage increases and therefore the voltage stress, any free ions present will be set in motion, causing other ions to be formed by collision with neutral molecules. These ions are moving toward the positive electrode to be discharged. If the positive electrode is near the negative electrode, the ions will be discharged, and a further increase in voltage stress is necessary in order to produce a sufficient number of ions to cause the dielectric to become conducting by breakdown. If the positive electrode is not close to the negative electrode the ions do not have time to reach the positive electrode before a large number have been produced in the region of the negative electrode. This may result in the dielectric around the negative electrode exhibiting the properties of a conductor and the electrode has been virtually extended into the substance of the dielectric. This will result in a greater increase in the number of ions without further increase in voltage and finally, puncture will occur. The voltage necessary to cause breakdown will not be proportional to the voltage required for small distances between the electrodes. In the case of alternating voltages, there is the additional consideration that the time phase is likely to change before the ions have been able to discharge, so that they will simply accumulate around the electrodes and the dielectric will become conducting at the electrodes with the results previously stated. Is the current Mr. Peaslee refers to at different parts of the insulation the ionization current described above. The writer believes it is and that his curve of current density can be explained by ionization of the dielectric as the voltage is increased.

It may be of interest in connection with Mr. Shanklin's reference to "energy distance" to report that calculations were made for the data given in the paper with the following results.

The value of the voltage stress was computed at a radius equivalent to that for the energy distance as found by means of the ionization formula for each table. The voltage stress at the energy distance should be constant. The following average deviation was found for each table.

Table	I	II	III	IV	VI
Average dev. per cent........	10.4	6.0	0.1	7.6	0.3

For Table I, II and IV, the formula for K had a negative sign, whereas for Table III and VI, the formula for K had a positive sign. Although a constant value of K was not obtained for the stress at the energy distance for each table, in two cases it was practically obtained and for the other three, fair agreement obtained.

1. Theory of Corona, by Bergen Davis. PROCEEDINGS, A. I. E. E., Vol. 33, April, 1914.

THE AUTOMATIC TRAIN CONTROL PROBLEM*

(Blake), New York, N. Y., February 15, 1923.

Frank J. Sprague: I wish to refer to the tests which have been going on on the New York Central Railroad since the 20th day of February, a year ago, on so-called automatic train control. What is the object sought in train control? Simply to marry together the traffic conditions which exist on a railroad, no matter how indicated or governed, whether by manual signals or by automatic signals, with the braking system of a train in such manner as to insure the complete protection of that train movement, the reinforcement of any wayside indications, the amplification of those indications in the cab of the engine, or their replacement, without encroaching upon the prerogatives of the engineer when properly exercised, and without limiting the capacity of the railroad operation.

That means not an "automatic stop" in its simple form, because it has little value on a modern railroad system. It has to be placed either too far back, so as not to interfere with traffic, or too far forward, so that it will not itself protect traffic. Nor must there be an automatic system, in the sense that trains are to be run automatically. It must be an auxiliary system, something which leaves to the engineer that which properly belongs to him, the handling of his train according to the great varieties of conditions that exist in operation, all the while protecting him, but in no case unnecessarily interfering with him.

Therefore the system should be called an "auxiliary" and not an automatic, system of train control, one where operation is automatically initiated, but under the control, so far as proper, of the engineer himself.

There have been several systems mentioned. They may be divided into two broad classes. First, intermittent; and, in this class, we have the rail-contact ramp devices, also the inductive method of initiating impulses on the locomotive, either by induced electromotive forces in the control circuits, or by direct magnetic action; and then there is on the other hand the so-called continuous system, illustrated by wireless or by the picking up of induction from the rails themselves, as well as other methods unnecessary to mention at the present moment.

Train control has had a hard road to hoe, as those who are interested in it know. There have been over a thousand proposals before the United States Government, and one of the leading signal engineers of the country said there had been over four thousand proposals before the railroads.

Opponents of train control have largely ignored the possibilities of a properly developed system, the making less necessary, or insuring a simplification or reduction in the use of wayside signals,—leaving out for the moment the making possible a two-way operation of every track of a multiple-track railroad, with cab signals operated in either direction of traffic. Those are perhaps the two larger results to be obtained, not merely the humanitarian one.

The United States Government, however, has looked more particularly to the matter of safety, and the Interstate Commerce Commission recently has ordered 49 railroads in this country, to each equip, within two years, a complete engine division in certain specified localities. Their order covers only a very small proportion of the mileage of the large railroads, but this work has got to go ahead now and in the course of two years there will be a goodly number of systems in operation.

Some will bring, no doubt, disappointing results to the railroads, and with the possibility of inducing dangers which they were intended to eliminate. Some of these cannot be avoided, but we hope, as to others, the results will be satisfactory. Up to the present the few systems in use in this country are of the so-called rail-impact type.

This has one fundamental and serious objection, which I will specify and illustrate by reference to three exhibits laid before the Government at Washington. It is based upon the idea that at every block over which a train passes there must be operated a shoe whose object it is to apply the brakes, but such application is to be prevented when the block is clear, by the supply of electric current to that particular ramp rail.

You would be surprised to see and know perhaps how few times automatic operation should be called into play. I will illustrate very briefly by facts taken from the official records:

On three railroads, which I will designate as A, B and C, we have the ratio of needed brake applications to the number of blocks passed over as follows: A, 1 in 414; B, 1 in 1491; and C, 1 in 37. If you have an apparatus which is operated every time you go past a block, it is operated a hundred or more times, as frequently as called upon by adverse traffic conditions.

The great difference between that kind of a system and the induction system, no matter of which type, is that the apparatus operates only when it is required, and not the many times not necessary. In other words, it is required probably on an average of perhaps once in one hundred blocks, based upon the average density of train service in the United States.

The Joint Committee of the American Railroad Association and the Interstate Commerce Commission about a year and a half ago started to have certain sundry tests made in this country, and among others there was one initiated by my own company, carried on on the New York Central Railroad on the No. 2 track, the same track used by the 20th Century. It started a year ago and for the past two months it has been under closed sealed tests. Some idea of the intensity of that test may be indicated when I state that the number of brake tests have been from thirty to five hundred as many as occurred on the roads above mentioned, and the brake applications made during the two months just closed is what would have occurred, in average density of operation, on a train five times encircling the globe at the Equator.

Mr. Blake's paper omits reference to what has been done over a very considerable period, and those facts should ultimately be placed upon the record.

Azel Ames: It is to be regretted that Mr. Blake uses the word "engineer" throughout to denote the locomotive operator rather than the official designation of "engineman". It is suggested that the terms "main line" and "terminal" territory would be more precise than the terms "block signaling" and "interlocking" territory used in paragraph 9 for the reason that nowadays automatic blocking is carried through all main line interlockings and automatic train control would naturally be carried through them when installed on any given section of main line. In terminals where slower speeds are called for, automatic train control would of course be less necessary and vastly complicated.

The author points out the superiority from the safety standpoint of "continuous" as compared with "intermittent" control and also the greater facility which "continuous" control offers for the installation of cab signals. On the other side it may be said that with existing types of continuous control considerable inconvenience is likely to be encountered especially with work or construction trains due to the impracticability of pushing cars, snow plows, or other types of equipment ahead of the engine. It is also well to remember that while the principal protective feature of "continuous" control lies in causing a stop application in the event of a switch being opened or a train pulling out of a siding after the approaching train has entered the block, we cannot be sure that these untoward events will always happen when the approaching train is full braking distance, or even half that distance from the point of obstruction.

In noting that all speed controls of the "braking curve type" require the automatic control indication to be effective at a uniform distance from all stop signals, the author is undoubtedly assuming level track conditions, as the distance would vary with the grade of the approach to the stop signal.

Mr. Blake's paper refers principally to the signaling and train

*A. I. E. E. Journal, 1923, Vol. XLII, January, p. 27.

spacing features of the automatic train control problem and to the various means employed to produce an impulse or effect in the engine cab as the result of certain conditions upon the roadway. It would have been very interesting if he had touched upon that much neglected phase of the problem, namely, that of braking. For years discussions of automatic train control have seemed to assume that if a magnetically controlled valve somewhere in the braking system could be opened to permit a reduction of air pressure when it was desired to stop a train, the problem had been solved. Our present highly efficient automatic brake systems have been designed entirely for manual operation and many of their characteristics might be quite different if they had been designed for automatic control. Perhaps the most serious phases of the automatic train control problem after all are the great variety in the braking power of trains, especially freight trains, the large time elements involved in application and release in long trains, the necessity for release to accomplish a second application on long down grades and the enormous cost of changes in the existing equipment.

Most of these are matters for mechanical rather than electrical solution, but it is very desirable that the electrical engineer studying automatic train control should realize that it is the brake that must stop the train and that his electrical apparatus and circuits must be designed with the characteristics of the braking system always before him.

T. S. Stevens: Quoting from page 27: "The primary function of automatic train control is, of course, to stop the train before it enters upon unsafe territory."

This has been true with reference to older developments, but the tendency now seems to be to stop the train only when the engineman fails to properly reduce speed.

Page 32: "Furthermore the number of speed indications which can be intelligibly given by semaphore is limited while any reasonable number of indications can be provided for in the cab."

This sentence seems to be definitely at discord with the actual conditions. While I do not agree with the signaling methods used on a considerable mileage of the railroads, largely because of the lack of necessity for a large number of speed indications, the facts are that on very many railroads, where three-arm signals are used, quite a number of varied speed indications can be provided intelligibly which are absolutely impossible to provide in the locomotive cab. So far, if the stop indication is included, the manufacturers have been able to provide four speed indications: high, medium, slow and stop. As a point of fact the majority combine the slow and stop indications so that only three are provided.

M. E. Pipkin: Mr. Blake's paper gives the impression that the author considers continuity of indications on the engine a highly desirable feature in train control, if not an absolute essential. In this connection, it is interesting to compare the situation with that which obtains in the present roadside signal systems. In the roadside systems and in all of the automatic systems described by the author the track is divided into definite blocks and the control required is with definite relation to these blocks. Specifically the requirement is that the train stop at a definite point, namely at the entrance to an occupied block. Furthermore, the indication that a stop is required becomes effective in all cases at a definite location namely, the beginning of one or another block section. In the case of roadside signals, the necessary warning is given at the logical point, namely the point where it becomes effective. In other words the fixed roadside signal is essentially an intermittent indication confined to a definite location for each block, precisely as is true in the case of the intermittent control systems described. In both cases the control of the indication including track circuits and control circuits from the opposing train back to the actual indicating point is properly continuous, but the indication itself is intermittent.

E. J. Blake: Mr. Sprague's discussion emphasizes effectively two points mentioned in the paper; the necessity for avoiding anything that will supersede the engineman when he functions right, and the insufficiency of the plain automatic stop when traffic capacity has to be maintained. I agree with him that we can expect, and should provide for, simplification of roadside signalling and increased facility of train operation, as well as increased safety with the adoption of automatic train control. That has been the history of roadside signalling. It was introduced as a safety measure, but has become recognized equally as a measure for facilitating train movement. The particular case cited by Mr. Sprague is not altogether peculiar to automatic control; two way operation of multiple tracks has been provided for in a number of cases by the use of roadside signals.

Mr. Sprague does not make wholly clear just what is meant by the "ratio of needed brake applications to the number of blocks plassed over." If he means that the engineman disregarded stop indications so that automatic control should have come into play in one block out of every 414, or 1491, or 37, the last figure seems surprisingly small. In any case we can agree that actual operations of the automatic control necessitated by failure of the engineman ought to be exceedingly infrequent. But it does not seem especially important what the control apparatus does the ninety nine times it is not required (assuming that it does not interfere with the operation of the train). The essential thing is certainty of operation in the hundredth case when it is needed. We have a somewhat similar case in roadside signalling. The signals ordinarily operate at the passage of every train, irrespective of the presence of a following train for which the signal indication is required. It is to be hoped that the results of the New York Central tests to which Mr. Sprague refers will be published in due time.

Major Ames's comments on the terminology of the paper are well founded. "Engineman" "main line" and "terminal" territory are more precise than the terms used in the paper. I cannot agree with him that the principal advantage of continuous control from a safety standpoint is response to danger arising after the train has entered the block. It has this advantage, but as Major Ames points out, nothing can protect a train against a danger that arises too near it to permit of stopping. The fundamental claim of the continuous systems to superior safety as I see it is the fact that they can be arranged to respond to *every* cessation of energy as a danger indication, just as is true of roadside signal apparatus. Every intermittent system necessarily responds to some *action* at the indicating point so that absence or failure of the action is, in effect, a false proceed indication. Protection for equipment pushed ahead of the locomotive is a real difficulty; but in the case of work trains at least it would seem reasonable to operate with the automatic control cut out, just as they are frequently operated under "work orders" without regard to fixed signals or the direction of traffic.

The reference to uniform location of control indications for "braking curve" control should have been qualified as suggested with regard to grades.

Major Ames points out that proper air brake control after suitable traffic indications have been received is a serious problem in itself. This is true in some degree for all control cycles, and particularly, for the cycles based on slowing down to a prescribed speed at caution signals; for in this case the automatic device must check the sufficiency of the brake application even when it is initiated by the engineman. But it should be borne in mind that the automatic control is intended to stop the train only as a last resort in the infrequent cases where the engineman fails to do so. Under the circumstances, rough and even dangerous handling of the brakes might be tolerated in preference to continuing to run unchecked into the obstruction.

The first passage quoted by Mr. Stevens, when read with the sentence which follows it seems to say substantially what Mr.

Stevens says in his comment. But the second passage (page 32) may be unintentionally misleading. It is true that the number of simple and desirable aspects available with semaphore signals is limited because the semaphore (and its light indications at night) must be read at long range and under unfavorable conditions; and it is true that no such limitation exists for cab signals. As an extreme illustration the engineman is able to distinguish clearly seven hundred and twenty distinct minutes in twelve hours on the face of his watch. But it is not true that unlimited indications can be transmitted from the roadway to the train without very great complications. Practical developments to date have been confined to the simplest available circuits giving three or at most four indications on the train as stated by Mr. Stevens. It is likely that these indications will suffice for a great majority of future installations; but it is far from impossible to give a much larger number if the need should justify the cost.

Mr. Pipkin cites an interesting parallel between train operation under roadside signals and under automatic control, and concludes that intermittent indications on the train are a logical result of the subdivision of the track into blocks at definite points. The analogy is not wholly valid because the roadside signals are commonly visible through a considerable part, and often through the whole of the block. In the latter case the indications received on the trains are strictly continuous, notwithstanding the intermittent location of the signals themselves. Furthermore the point at which action is required to bring the train to a stop at the entrance to a block is not definite but varies with the speed of the train. An engineman approaching a stop signal often sees the signal change to caution before he is obliged to set the brakes; or sees the signal change before the train has come to rest, releases his brakes and proceeds. In either case he is taking advantage of a continuous indication, extending back to the visible range of the signal. It is the universal custom to locate roadside signals with a view to getting the longest practicable range of visibility—that is to give continuous indications to the engineman as nearly as possible; and even where the range is shortest the indication is by no means comparable with an instantaneous impulse during passage by a definite point.

DISCUSSION "ON A NEW EQUATION FOR THE STATIC CHARACTERISTIC OF THE NORMAL ELECTRIC ARC"* (NOTTINGHAM),

New York, N. Y., February 16, 1923

W. N. Eddy: As a supplement to his detailed analysis of the voltage-length-current characteristics of short arcs Mr. Nottingham might be interested in the results of some arc tests that were published in 1922.[1] These tests were made with the idea of (1) trying out Dr. Steinmetz' equation at longer arc lengths than used by him in 1906 and (2) finding the effect on his equation of different pressures on the arc stream.

While developed from data on arcs no longer than 2 in. the Steinmetz equation was found to hold true for arcs as long as 6 in. the maximum length of arc tested.

While the Nottingham equation satisfactorily represents the short arcs the longer arcs show a straight line relation between length and voltage and therefore are better represented by the Steinmetz equation. Thus it would seem that a combination of the two equations should satisfactorily represent the volt-ampere-length characteristics of normal arcs throughout the whole range of length.

The effect of the pressure on the three different constants of the Steinmetz equation was shown empirically in the form of curves for various electrode materials. By the use of these curves the Steinmetz equation can be used to show the relation of the five variables current, voltage, length, electrode material and pressure on the arc stream.

W. B. Nottingham: In answer to Mr. Eddy, I wish to call attention to the statement in my paper that "It is evident from this examination of the equations (19) and (21) that arcs of less than 15 mm. (length) can not possibly be represented accurately by an equation less complex than equation (19). However, arcs of length greater than 15 mm. can be represented by equation (22), which is the limiting form of (19) for large arc lengths; *viz.*

$$E = A + B\,L + \frac{C + D\,L}{i^n} \qquad (22)$$

E = Difference in potential across the arc.
L = Length of the arc.
i = Current in the arc.
A, B, C, D, and n are constants depending upon the electrode material, the surrounding medium, etc.

Equation (22) shows the difference in potential (E) across the arc to be a linear function of the arc length (L), and therefore it agrees with Mr. Eddy's observations. When equation (19)

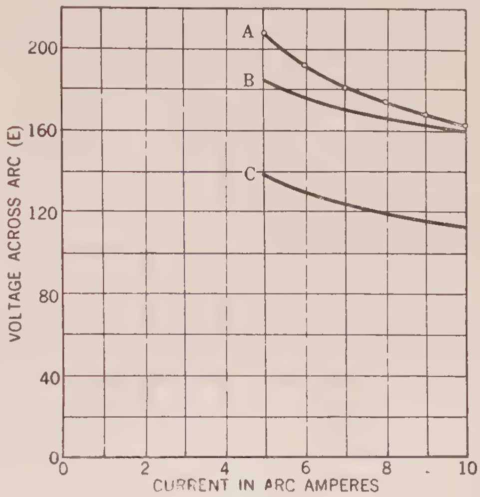

FIG. 1.—A CHARACTERISTIC CURVE FOR AN ARC BETWEEN COPPER ELECTRODES ARC LENGTH = 5 CM.

A Grau and Puss Observed.
B Nottingham Calculated.
C Steinmetz Equation. Constants from W. N. Eddy.

is used for long arcs (15 mm. or more) the only differences between it and the Steinmetz equation are that the current enters as i^n instead of $\sqrt{i}$ and that there is a term $\gamma\infty\ L$ (or $B\ L$ in equation (22)) which is omitted from the Steinmetz equation. *In both equations the voltage is a linear function of the arc length.*

Fig. 1 has been prepared to show that equation (19), or its limiting form equation (22), holds quite well over a range far greater than that for which its constants were originally calculated. The three curves shown in the figure are; (A) the characteristic curve for an arc 5.0 cm. long between copper electrodes as observed by Grau and Russ[1]; (B) the characteristic curve for a copper arc of the same length calculated by equation (19) (or equation 22), using the constants given in Table VII[2]; and (C) the calculated characteristic for the same arc using the Steinmetz equation with constants given by Mr. W. N. Eddy[3] for the normal arc between copper electrodes in air at atmospheric pressure.

*A. I. E. E. JOURNAL, Vol. XLII, January, p. 12.

1. Length-Voltage-Current Pressure Characteristics of Normal Arcs for Different Electrode Materials, *G. E. Review*, March 1922.

1. Grau and Russ, *Phys. Zeitschr.*, 9, p. 107, 1908.
2. A. I. E. E. JOURNAL, Vol. XLII, p. 16, Jan. 1923.
3. W. N. Eddy, *G. E. Review*, March 1922, p. 191.

Steinmetz Equation:

$$E = a + \frac{c\,(l + \delta)}{\sqrt{i}}$$

a = 48.8 volts
c = 38.5
δ = 0.28 cm.
} W. N. Eddy's constants for arc between copper electrodes in air at atmospheric pressure.
l = Arc length in cm.

It was the aim of my paper to present an equation to represent satisfactorily "the volt-ampere-length characteristics of normal arcs throughout the whole range of length." Equation (**19**) meets this requirement in every way that I have been able to test it.

PHYSICAL INTERPRETATIONS OF COMPLEX ANGLES AND THEIR FUNCTIONS*

(Boyajian), New York, N. Y., February 16, 1923

A. E. Kennelly: I think we are all indebted to Mr. Boyajian for bringing to our notice that we shall have to modify our views concerning angles, and their treatment by engineers.

I think that has been evident to a great number of us, but Mr. Boyajian has been the first to say so definitely. He has shown us how complex angles may be worked. I think that the method he gives is workable and reliable, but I would like to make one reservation in regard to the treatment that he offers.

I think we all agree in regard to what he says about circular angles, and that a hyperbolic angle is an imaginary circular angle, also that a circular angle is an imaginary hyperbolic angle, but he takes the position, if I understood him correctly, that for a hyperbolic angle, it is not necessary to involve any kind of rotation, that it is simply a one-dimensional movement, or a one-dimensional quantity.

I think that while for ordinary purposes that may be true, and that processes of calculation may be conducted on that basis, but to say that the hyperbolic angle is of one-dimensional quantity, is I believe, limiting it unnecessarily. It seems to me that we can use Mr. Boyajian's method without necessarily confining ourselves to that point of the doctrine. I still think that we can maintain the idea of rotation through an area in connection with a hyperbolic angle, and one reason for that is presented in these slides of a model for projecting the cosines and sines of a complex hyperbolic angle, and which attributes rotation of a radius vector to both the hyperbolic and circular components of the complex angle.

A. Boyajian: As for the reservation which Dr. Kennelly wishes to make so as to maintain the idea of rotation in connection with hyperbolic angles, may I submit the following considerations:

When the radius vector traces a hyperbolic sector, it certainly also traces a circular angle by virtue of its rotation. According to usual schemes, the area of this hyperbolic sector is made use of to represent the numerical value of the hyperbolic angle, and the circular angle which the radius vector has traced is ignored. As I have stated in my paper this is permissible representation but is not completely illustrative of the essence of a hyperbolic angle. If we were called upon to make a representation of a hyperbolic angle, in which there shall be no trace of a circular angle, I think we shall have to fall back on the straight line diagram given in my paper in accordance with the newer point of view.

Dr. Kennelly feels that to make the hyperbolic angle a one-dimensional quantity, that is, to eliminate rotation from the representation of hyperbolic angles, limits them unnecessarily. I feel however that the idea of rotation which has been forced on hyperbolic angles in the past has unnecessarily handicapped the interpretation of the true physical nature of hyperbolic angles. The new point of view, by eliminating this unnecessary condition of rotation, gives greater freedom to the hyperbolic angles and to their interpretation.

*A. I. E. E. Journal, 1923, Vol. XLII, February, p. 155.

TELEPHONE TRANSMISSION OVER LONG CABLE CIRCUITS*

(Clark), New York, N. Y., February 15, 1923

James J. Pilliod: Metallic conductors interconnecting cities and territories must be used in ever increasing quantities to meet the requirements for long distance telephone service. For many conditions, open wires carried on pole lines provide the best method and the one with which we are all generally familiar. The other available method and the one with which this paper specifically deals, is to bunch the wires together within the limits of a small lead sheath and this, as might well be supposed, introduces new problems and some of the most important of these are problems of transmission. The two methods mentioned are complementary and both have wide fields of application.

For some sections of the country the cable method of providing for the service offers advantages which are of almost controlling importance and it is to some of these advantages that I will briefly refer in the following discussion.

Continuity of service is of prime importance under all conditions, but to insure this in a substantial degree in the case of heavy open wire lines under extreme weather conditions requires very expensive construction. The cable method is, therefore, an important step in the direction of providing greater insurance to continuous service. The successful development of the telephone repeater has made it possible to operate long telephone circuits by the use of wires of a smaller gauge than good engineering practise requires from the standpoint of mechanical strength in the case of open wire lines. To use these smaller conductors, means, therefore, that the wires must be placed in cables.

These cables are practically free from damage due to sleet and wind storms, and while an occasional interruption to service is likely to occur, just as a leak might develop in the roof of this building, still such interruptions are of less consequence than if the structure as a whole were badly damaged.

From the standpoint of conservation, as many as 300 long distance telephone circuits can be provided in one cable and several cables can be carried on one pole line. To provide for as many circuits as can be placed in one cable with open wire construction would require ten pole lines, using poles of considerably greater size. As is well known, timber is becoming scarcer each year and the number of available through routes not already occupied with pole lines is extremely limited. It is easy to imagine the difficulty that would be experienced in trying to find routes for ten to twenty new pole line routes at this time between New York and Boston or New York and Washington, but this, and even more, would be required if cable could not be used for telephone circuits connecting these points. The same applies to the section generally between New York and Chicago and between other points. Another item is the matter of copper. For the 300 circuits on the basis of open wire lines, we would require at least 70,000 lb. of copper per mile, while for three hundred circuits in cable, 13,000 lb. is sufficient. Therefore, for each mile of cable we leave 57,000 lb. available for other purposes.

I believe that these few examples make it sufficiently clear that the development work, an important part of which is described in this paper, which has been done to make it possible to operate long distance telephone circuits in cables is of great importance from the standpoint of conservation and economies and from the standpoint of reliability of service which the people of this country not only expect, but require and demand.

*A. I. E. E. Journal, 1923, Vol. XLII, January, p. 1.

It will, however, be evident from a reading of the paper that to obtain these things it is necessary to be liberal in the expenditure of technical ability.

I have been very much interested in the diagram showing power levels at the various points along a New York-Chicago cable circuit as illustrated in Fig. 7. The discussion of this, as well as the requirements for considering velocity of propagation, echoes, and transmission regulation to compensate for variations in attenuation due to temperature changes illustrates forcibly the necessity of careful design and a consideration of circuits from one end to the other as a unit if satisfactory results are to be obtained.

DISCUSSION ON "PERMEABILITY"* (SPOONER)

New York, N. Y., February 16, 1923

E. L. Bowles: Mr. Spooner has presented some very interesting data concerning an involved and difficult subject. The analysis of circuits containing what are rather equivocally called "variable constants," is a difficult and sometimes an impossible problem. At present we are faced with a very serious situation no matter which way we turn. Variable coefficients of resistance are met with in the case of gaseous or thermionic conduction, and they are met with also in the case of circuits containing magnetic materials. In fact, even dielectrics suggest the consideration of variable coefficients. In view of these conditions, it seems that we should talk of the *Coefficients* of an electric circuit rather than the *Constants*, for after all, in developing the subject, one must overcome the handicap which results from a treatment of the electric circuit on the basis of constants.

Thus far, circuits with variable coefficients have required the use of Fourier series, Fourier integrals and integral equations. Many analyses are so involved that one loses sight of the very principle or purpose. Unless a great simplification is made in our treatment of such problems, we will have to rely almost solely upon empirical, or else cut-and-try methods. Perhaps it will be possible to develop a number of graphical solutions wherein the volt-ampere or other characteristics are used as the foundation. Graphical methods have been applied in the determination of the operating characteristics of generators and motors. To a certain limited extent, they have been applied to thermionic problems, and it is the writer's feeling that this method of attack may ultimately become a very fruitful one.

It is hard to place general confidence in Mr. Spooner's special results, since the assumptions made are likely to mislead one rather seriously. The question of what happens in a choke coil used for radio frequency is as yet unanswerable, owing to the complexity of the conditions involved. Conclusions based on low frequency analyses can hardly hold in such cases. The reactance of an iron circuit depends not only upon the phenomenon of hysteresis but also upon the eddy current loss. The separation of these two is difficult, and in some cases it is impossible.

Another point to be brought up is the question of the inductance of a circuit containing variable coefficients. In a circuit containing a magnetic material of variable permeability, it is not possible to speak of such a thing as a constant inductance L, but rather to speak of another variable or instantaneous inductance l for the induced voltage is by fundamental concept:

$$e = -N \frac{d\,\phi}{d\,t} \times 10^{-8} \text{ volts}$$

$$= -N \frac{d\,\phi}{d\,i}\,\frac{d\,i}{d\,t} \times 10^{-8}$$

or

$$e = -l\,\frac{d\,i}{d\,t} \qquad \text{volts}$$

*A. I. E. E. JOURNAL, Vol. XLII, January, p. 42.

where

$$l = -N \frac{d\,\phi}{d\,i} \times 10^{-8} \text{ henrys}$$

If now the permeability is constant, then the derivative of flux with respect to current is constant, or:

$$L = \frac{N\,\Phi}{I} \times 10^{-8} \text{ henrys}$$

which is the familiar expression for inductance ordinarily used, or

$$e = -L\frac{d\,i}{d\,t} \text{ volts}$$

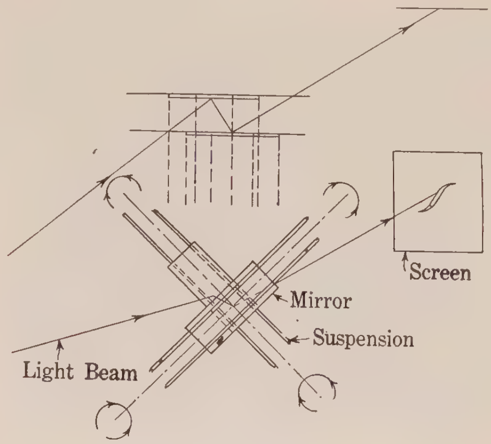

FIG. 1

The Research Department of the Massachusetts Institute of Technology has spent considerable time during the last three years in attempting to exactly determine the dynamical conditions existing in a magnetic circuit containing iron. Much work has been done in the development of a special bi-vibrator-quadrantal oscillograph. This idea is not new, nor was its application new in this particular case. This oscillograph consists of two vibrators facing each other, and at right angles. A beam of light striking one of the mirrors is reflected to the other, and then reflected once more, as shown in Fig. 1. In this way, a compounding of the motions of the two mirrors will produce the

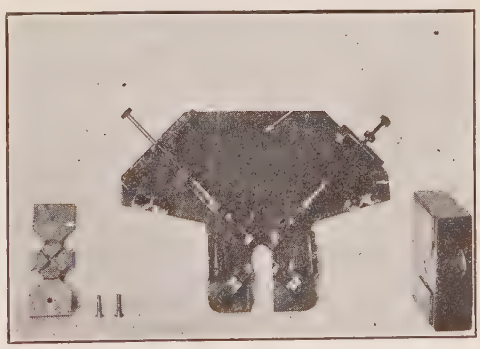

FIG. 2

well known Lissajous figures in the case where the two motions are harmonic. If the deflection of one of the vibrators is made porportional to the magnetizing force, and the deflection of the other proportional to the flux, such an oscillograph is capable of tracing hysteresis loops visually so that they can be directly photographed.

The parts of the completed oil-damped oscillograph are shown in Fig. 2. One of the vibrators is capable of rotating about an axis parallel to the axis of the suspension, and the other vibrator

is capable of rotating about an axis lying in and perpendicular to the mirror. Thus the beams from the two mirrors can be made to trace orthoganal lines on a screen or negative. The completed oscillograph, with its magnets, is shown in Fig. 3.

The research problem has resolved itself into the determination of a circuit which would carry a current proportional to the flux. An example of a particular circuit with the vibrators inserted is shown in Fig. 4. Neglecting the leakage reactance of the coil B, we have that

$$e = N \frac{d\,\phi}{\phi\, t} = R_o\, i_o + L \cdot \frac{d\, i_o}{\phi\, t} \quad \text{volts} \qquad (1)$$

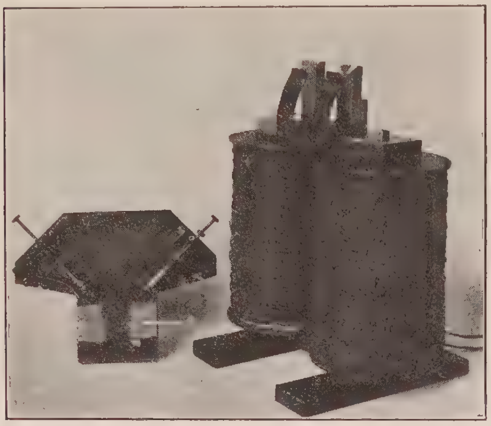

FIG. 3

And the solution of this equation, neglecting the transient term, is:

$$i_o = K\, \epsilon^{-\frac{R\,t}{L}} \int \epsilon^{-\frac{R\,t}{L}}\, d\,B \ldots \quad \text{amperes} \qquad (2)$$

If now R_o is negligible, we have the result:

$$i_o = K \int d\,B \quad \text{amperes} \qquad (3)$$

So that if an oscillograph vibrator were inserted, as in Fig. 1, at any instant its deflection would be proportional to the flux in the iron.

Some idea of the validity of the assumption of negligible

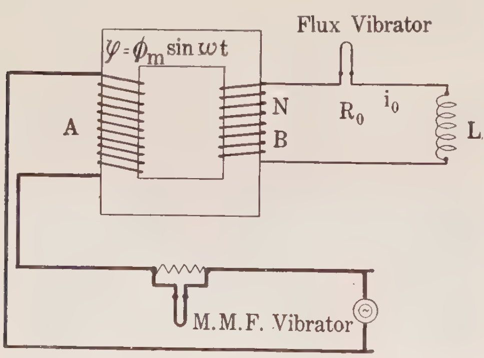

FIG. 4

resistance can be obtained if certain conditions are taken. For example, if a sinusoidal voltage is impressed on the magnetizing coil A of Fig. 1, then the flux will be a sinusoidal. With this condition, the exact steady state solution of equation (1) is:

$$i_o = K_1 \frac{\omega}{R_o^2 + L^2\,\omega^2} \left[B \pm \frac{R_o}{L\,\omega} \sqrt{B_m^2 - B^2} \right] \quad \text{amperes} \qquad (4)$$

Or by expansion in which all terms except the first are neglected, equation (4) becomes:

$$i_o = K_2 \left[B \pm \frac{R_o}{\omega\, L} \sqrt{B_m^2 - B^2} \right] \quad \text{amperes} \qquad (5)$$

From which the per cent deflection error, η_ϵ, for a major loop is:

$$\eta_\epsilon = \frac{\frac{R_o}{\omega\, L} \sqrt{B_m^2 - B^2}}{B} \quad \text{numeric} \qquad (6)$$

FIG. 5

FIG. 6

It is seen that the error is zero when $B = B_m$, and a maximum when $B = 0$, or:

$$(\eta_w)_{max} = \frac{R_o}{\omega\, L} \quad \text{numeric} \qquad (7)$$

The area represented by the error term is of the form of an ellipse. In order that the area of the ellipse be negligible, R_o must be very

low, or L very high, or both. For frequencies in the power range, L would need to be impractically large. It was attempted to make R_o small by the use of a dynatron, but difficulties were encountered which at that time, at least, could not be overcome. With no corrections for resistance, J. P. Putnam, in his Bachelor's Thesis (1921), secured some very interesting oscillograms which are shown in Figs. 5 and 6. (These were obtained with an experimental instrument as first used.) In Fig. 5, a very interesting effect is noticeable. The tips of the successive loops do not follow the magnetization curve as one ordinarily imagines. Fig. 6 shows the effect of a direct component of current in an iron core. These curves suggest points of considerable interest which can only be investigated by dynamical methods of hysteresis loss determinations.

Another method of securing a current through the flux vibrator proportional to the flux is to replace the inductance L, shown in Fig. 1, by a high resistance in series with a condenser. The difference in potential between the terminals of the condenser is:

$$v_c = 1/c \int i\, d\, t \quad \text{volts}$$

But if R_o is large, then

$$v_c = \frac{1}{R_o\, C} \int e\, d\, t \text{ volts}$$

And since the integral of voltage is flux:

$$v_c = \frac{1}{R_o\, C}\, \phi \text{ volts}$$

where ϕ is the instantaneous flux. The error is of the same nature as in the case of the inductance, and is expressible by:

$$(\eta \epsilon)_{max} = \frac{1}{\omega\, R_o\, C} \text{ numeric}$$

The two methods mentioned are impractical as they stand, but a third method is now being worked upon, which promises to yield results which will be accurate, under the condition that the laminations making up the magnetic material under test are so thin that the effect of eddy currents is negligible.

G. H. Cole: Mr. Spooner's paper is of value to the designing engineer rather than to the mathematical physicist. It is quite probable that in the majority of design calculations involving incremental permeability, its value is simply guessed at. Fig. 5 of Mr. Spooner's paper shows that the ordinary permeability may be several times as large as the incremental permeability and hence the use of this value instead of incremental permeability may result in large errors, while Mr. Spooner's simple formula quickly gives the incremental permeability of sufficiently good accuracy for most practical purposes.

For the benefit of engineers who are accustomed to measuring electrical quantities with errors of less than a per cent, it may be well to mention that the standard method of measuring ordinary permeability of sheet steel may introduce errors, if the permeability is very high, of the same magnitude as the difference in the incremental permeability given by the Spooner formula and the test values recorded in Table VII covering a variety of materials of quite different magnetic properties. Even though the ordinary permeability may be accurately determined on specimens, the variation throughout the lot of steel from which the samples are chosen may be of the same order as those of the incremental permeability expected from the Spooner formula. This formula therefore, seems to be of sufficient accuracy for most applications and enables the designer to quickly estimate this characteristic of steel concerning which so little is generally known.

T. Spooner: With reference to the calculation of incremental permeability where the frequency is sufficiently high or the thickness of the laminations sufficiently great so that skin effect is appreciable Mr. Bowles points out that this method does not give reliable results. This is, of course, true as we have taken pains to mention in the paper. We hope to go into this aspect of the subject at a later date.

With reference to this new oscillographic arrangement mentioned by Mr. Bowles I had the pleasure a year or so ago of seeing some hysteresis loops taken with this apparatus. These loops were rather far from true hysteresis loops due to the fact that the resistivity of the secondary circuit could not be made negligible. This, of course, introduced very appreciable errors. It is to be hoped that this apparatus can be developed so that the resistance factor will be negligible since there would then be available a very valuable method of analyzing magnetic circuits under these special conditions.

It is a very easy matter to take a ring or other suitable sample of laminated steel which is provided with the necessary windings and to measure the effective permeability for various conditions of superimposed d-c. flux simply by reading the voltmeter and ammeter. We have done this in a few cases and in general have obtained fair checks with the value as calculated from the curves and formula based on ballistic results. There are some marked discrepancies, however, which perhaps Mr. Bowles' oscillographic method can explain.

APPLICATIONS AND LIMITATIONS OF THERMO-COUPLES FOR MEASURING TEMPERATURES*

(Smith), New York, N. Y., February, 16, 1923

E. D. Tanzer: Not so long ago, a thermocouple was solely a physicists instrument. At the present time, however, it has a wide field of application among the operating companies. At least, we of the Philadelphia Electric Company, during the past three years have used it extensively in field determinations of the operating temperatures of cable duct lines, cable sheaths and transformer manholes, as well as in research problems pertaining to the operation of an extensive underground cable system.

Mr. Smith has defined very nicely some of the limitations inherent in the use of various types of couples in the field. We have experienced in our own investigations, some of these same factors, and accordingly I believe that it may be of interest to show some ways in which we have found the thermocouple particularly useful in the investigation of temperatures in our underground system.

In measuring temperatures in duct lines, carrying several cables, it is obviously impossible to get the thermocouple into a duct occupied by a cable. The only thing that we can do is to devise a means of readily locating a couple along an adjacent empty duct.

In the device utilized for this purpose a mandril carries the thermocouple. In the center of this mandril, the thermocouple junction, imbedded in a small copper block, is protected so far as possible from any mechanical injury that might result from pulling the mandril through a duct. The first of these devices made up to investigate a duct run of about 400 feet length, was made with these mandrils spaced at approximately 50 foot intervals. The little block of copper in which the couple junction is mounted, is for the purpose of providing a small amount of thermal capacity just at that particular point and so obviate the possibility of heat radiation or conduction away from the couple junction itself since this would mitigate against the accuracy of its indication.

In one particular duct line in which a large number of measurements were made we had a duct length of about 400 feet badly congested with cables. Accordingly, a great deal of heat was to be radiated and the operating temperatures were rapidly becoming large. Thermocouples made possible the exact determination of the existing temperature within this duct run and so gave the loading that could be used to advantage for the cables involved. The configuration of the duct run was such as to cause difficulty in determining temperatures at midlength locations. The

*A. I. E. E. Journal, 1923, Vol. XLII, February, p. 171.

leads from each of the 50-ft. spaced couples were all brought back to the one location enabling the operator to read the temperatures along the duct run with a minimum of effort.

Couples have also been used to determine the location of a leak beneath the street level in a steam service main. In this case steam was present in adjacent manholes but the exact location of the leak was not readily determinable from the surface of the street by ordinary methods. However, by checker-boarding the surface of the pavement and locating a couple at the center of each one of these squares, the temperatures attained by the couples served to indicate the particular point in the steam main which was giving trouble, to within a distance of approximately 3 ft.

I believe, therefore, that in the future, there will be more, of what I might call "out of the ordinary," applications of thermocouples to the problems of the operating companies. Accordingly, Mr. Smith's paper is very timely as it discusses some of the things which we cannot expect thermocouples to do. For instance, although the couple, by itself, is very accurate, yet it may be so mounted as to nullify a portion, or even a large part, of its accuracy. Particular attention, therefore, must be devoted to not only the couple itself, but to the mounting with which the couple is to be used.

G. H. Cole: Thermocouples, because of their simplicity are frequently used under conditions which have been given little thought. For example, even with somewhat more thermocouple experience than the average engineer, it is improbable that I would have hesitated about measuring the temperature of a brass block by putting a thermocouple junction at the bottom of a small hole ½ in. deep, as shown in Fig. 3 of Mr. Smith's paper, unless very good results were desired. Yet this procedure resulted in nearly as great a difference in the temperature desired and that read as between the mean temperature of May and December in New York City.

While it is well known that the temperature drop at surfaces of solids through which heat flows is relatively large, as for example at the junction of bricks in a furnace wall, Mr. Smith's paper has been of value in calling attention to the need for using this knowledge in thermocouple applications.

Due to the numerous surfaces to be crossed by heat flowing across a laminated transformer core, the thermal drop may 50 to 100 times greater in this direction than perpendicularly to it for the same distance in one lamination. The foregoing indicates the importance of making intimate contact with the surface whose temperature is to be measured.

I would like to ask Mr. Smith if surface drop and conduction errors can be largely eliminated by having the two thermocouple wires make contact with the body to be measured at different points.

R. P. Brown: Mr. Smith, in his paper, makes the following statements:

"Any change in the resistance of the thermocouple circuit causes an error in a millivoltmeter type of pyrometer or thermometer proportional to such change." He further states:

"With instruments of the potentiometer type, no error results from the above sources excepting a small one arising from change in sensitivity of the instrument due to a change in resistance of the circuit"—which he explains, with doubling the resistance of the circuit, might cause an error of 1 deg. cent. Mr. Smith further adds:

"On the other hand, a millivoltmeter would show an error at say 100 deg. cent. of nearly 50 deg. cent. and that this source of error is not readily determined with a millivoltmeter unless the whole be checked at some known temperature."

In making a comparison of the errors encountered in using a millivoltmeter pyrometer as compared to a potentiometer pyrometer, under conditions wherein a thermocouple circuit resistance is doubled, it is, of course, necessary to compare on the basis of the same thermocouple circuit conditions for each meter.

In the case of a millivoltmeter pryometer normally of about 600 ohms resistance and used with a thermocouple circuit of, say, one ohm resistance, it would be necessary for the thermocouple circuit to be increased to 600 ohms in order to halve the deflection of the millivoltmeter pyrometer.

For comparison,—in the case of a potentiometer pryometer, the same thermocouple circuit conditions must necessarily exist. In other words, the same change from one ohm to 600 ohms must take place. Mr. Smith, in his paper, states that an uncertainty of ½ deg. cent. normally exists. He then states that by reason of the circuit resistance being doubled, the uncertainty in reading becomes 1 deg. cent. instead of ½ deg. cent. This is not possible under the conditions encountered in the usual potentiometer furnished for such measurements. The slide wire resistance of such a potentiometer is normally approximately 30 ohms and the galvanometer resistance is approximately 20 ohms. It is therefore apparent that a change in the resistance from one ohm to 600 ohms in the couple circuit would far more than double the uncertainty existing in measuring with a potentiometer. Since the total circuit resistance increases from approximately 51 ohms to 651 ohms, it is evident that the uncertainty of measurement must increase in ratio of the resistance. In other words, the uncertainty of the balance will then be 13 times as great as originally, thus amounting to approximately 6½ deg cent., instead of 1 deg. cent. claimed by Mr. Smith. From this it is apparent that the comparison as made is incorrect, in that the same condition of thermocouple circuits have not been applied in making the comparison.

The only condition under which the comparison as stated would be substantially correct, is to assume that the thermocouple circuit, as referred to by Mr. Smith, applies only to the external circuit, including the thermocouple and its lead wires.

The average millivoltmeter pyrometer of today, put out by the majority of manufacturers, has an internal resistance of some 600 ohms. I have seen an instrument made by one of our competitors having a resistance of 1200 ohms and we frequently build instruments of this resistance ourselves, but to take an average condition, we can assume 600 ohms for the instrument.

A thermocouple most commonly used, 36 in. long, with 15 ft. of extension leads to convey the cold junction from the thermocouple to the instrument, has a resistance of ¾ of an ohm. Lengthening the extension leads from 15 to 30 ft. and increasing the thermocouple from 3 to 6 ft. long, would double the resistance of this circuit and would produce an error of only 1.3 deg. cent. in the readings of an instrument graduated, for example, to 1000 deg. cent. This is equivalent to only 0.13 of 1 per cent error (instead of nearly 50 per cent claimed by Mr. Smith.)

It is misleading to have a statement appear broadly implying that a millivoltmeter pyrometer would show an error at, say, 100 deg. cent. of nearly 50 deg. cent. on account of doubling the thermocouple circuit resistance.

The variation in temperature of the lead wires, referred to by Mr. Smith, will also produce exceedingly small errors in a modern millivoltmeter pyrometer. Assuming a length of lead wire of 100 ft., the change in resistance due to a change in temperature of 100 deg. cent, will amount to 0.1 ohm in a circuit of 600 ohms, or about 0.02 per cent. On a pyrometer reading to 1000 deg. cent. the error would amount to only 0.2 deg. cent. It is quite evident, therefore, that errors in a high resistance millivoltmeter, due to lead wire changes in temperature, are immaterial.

The only remaining possible cause for change in resistance in a millivoltmeter pyrometer, is the change produced by oxidation of the thermocouple. Claim is made that oxidation of the thermocouple results in an increase of thermocouple resistance, thus affecting the millivoltmeter pyrometer and not the potentiometer. The truth of the matter is that resistance errors due to oxidation are exceedingly small. Before the

deterioration of a thermocouple can be carried to such an extent that the resistance errors are appreciable, the e.m.f. of a thermocouple changes so badly as to render the thermocouple useless for measurements either with a potentiometer or a millivoltmeter.

When we compare the relative merits of the millivoltmeter and potentiometer for temperature measurements, let us not take for comparison a type of millivoltmeter which is not produced and compare it with a standard potentiometer.

I recognize the valuable features in both instruments—the millivoltmeter for its simplicity, the ease with which an unskilled operator can use it, its absence from standard cells, dry batteries and slide wires required in the potentiometer.

In the potentiometer I recognize its valuable feature in the entire absence, for practical purposes, of any errors due to changes in circuit resistance, and its value for extremely accurate measurements of temperature. Both types of instruments have their field and both have many valuable features.

I. B. Smith: The calculations made by Mr. Brown and myself may be carried out in a variety of ways. It seems hardly worth while, however, to go into details since Mr. Brown and myself appear to be in agreement as evidenced by his last remark, that one valuable feature of the potentiometer is "the entire absence for practical purposes, of any errors due to changes in circuit resistance."

VOLT-AMPERE METERS*

(Fryer), New York, N. Y., February, 16, 1923

P. A. Borden: I am pleased to see Mr. Fryer's reference to the advances which have been made in the use of volt-ampere meters in Canada, with particular reference to the Lincoln instrument. The Hydro-Electric Power Commission of Ontario, with which I am connected, is probably the largest user of the Lincoln meter, either with or without the so-called V.A.D. transformer. The Commission and the 300 municipalities to which it supplies power for resale use a large percentage of the number of these meters manufactured in Canada, and I may say that both those who sell and those who buy power as metered by this method seem satisfied with the principle as well as with its practical working out.

The combination meter, to which Mr. Fryer has referred as being developed by the Sangamo Company in conjunction with the Lincoln Company is, to date, I believe, a wholly Canadian product. A sample of this device is at present undergoing tests in the Commission's Laboratories. It combines a polyphase watthour meter and a Lincoln demand element, phase shifting for the latter being arranged for three different ranges of power factors, covering everything from about 40 per cent to unity with a theoretical error of less than 2 per cent. In this meter no attempt is made to integrate the volt-amperes. The integration is performed solely on a watt basis; while demand may be determined on either a watt or a volt-ampere basis, as desired.

A brief description of an ingenious volt-ampere meter developed some years ago by Mr. H. S. Baker may here be of interest. In some points this meter is not unlike the present volt-ampere meter produced by the Esterline Company, but it was in regular use some years before anything was published in regard to the latter instrument. Referring to Fig. 1, (which for purposes of clearness is shown as for a two-phase circuit,) we have first an element, consisting of the fixed coils, 1,1, and 2,2, together with the movable coils 3 and 4, thus constituting a power-factor meter. The rotatable element is normally in neutral equilibrium, and, consisting, as it does, of a polyphase winding in a polyphase field, will tend to take a position about its axis, representing the power-factor of the circuit, according to the "Second Definition" of the Institute.

*A. I. E. E. Journal, 1923, Vol. XLII, February, p. 123.

The moving part, however, has another function. It will be noted that the equatorial plane of this part does not coincide with that of the fixed part, and that the moving part is free, not only to rotate about its axis but to shift in the direction of that axis. It may easily be worked out that, the element having rotated into the position which represents the power factor of the load, the vertical thrust on the shaft will represent the value of the volt-amperes.

As shown in the diagram, this thrust is balanced by a counter-weight on a scale beam. In actual practise the beam carries contacts, which, through a relay mechanism, similar to that of the Westinghouse graphic instrument, produce an indication on a scale or chart. At the same time, by attaching a pointer to the moving element it is possible to directly read the power factor on a horizontal scale concentric with its axis. And if the moving element be locked from rotating, in the position corresponding to any chosen power factor, the instrument reads volt-amperes at that power factor; so that if it be locked in the unity position the device becomes a wattmeter. This scheme has been in use on the circuits of the Ontario Power Company since 1917, measuring some very important loads, and has proved of great value.

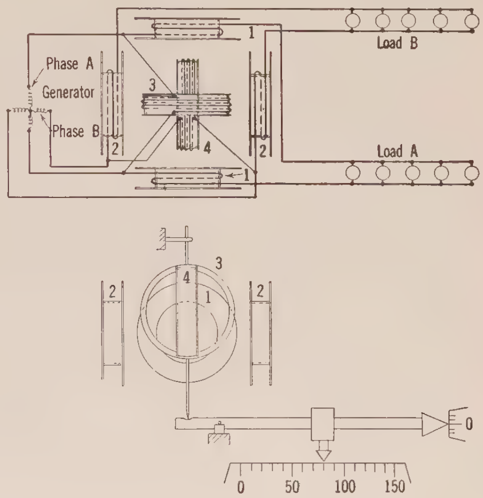

Fig. 1

Charles L. Fortescue: An accurate volt-ampere meter is very necessary for the actual determination of unbalanced factor; and I have been watching this development of volt-ampere meters with a great deal of appreciation.

I think that the balance method of measuring power, the balance factor will require a simpler device than volt-amperes on a polyphase circuit, as measured in the ordinary way, so that ought to help a little bit.

R. C. Fryer: I think the conclusions that might be drawn are these: That considerable progress has been made in the solving of the relation of power factor to the rate question. That considerable progress is being made towards the correction of poor power factors, and that the metering engineers in the industry stand prepared to offer practically any device that is desired for the measurement of volt amperes, whether it is taken by the first or second definition. The actual placing of the apparatus in use is now taking place. Several companies are actually using kv-a. meters in their billing department. We will have to recognize the fact, of course, that the practise will not, for a long time, become general. The reason I think is this: That a great many contracts are made on a five or ten-year basis, especially for the interchange of power. The result is that these contracts must run their life, before they can be

changed, and those that are in a position to change contracts now are so doing. Canada, it seems for some reason, has been a little bit more forward than the United States, in this direction at least.

MEASUREMENT OF TRANSIENTS*

(TERMAN), NEW YORK, N. Y., FEBRUARY 16, 1923.

E. E. F. Creighton: We have had so much difficulty with large spark lags in vacuums that I should like to ask Mr. Terman a question about his measurements. We have found in all sorts of vacuums a considerable dielectric spark lag and he has, I know, tested this with an oscillator where the duration of discharges can be expressed in thousandths of a second. But I should like to know if he has tried out the spark lag, using a frequency say of about five million cycles per second, and a single discharge.

F. S. Dellenbaugh, Jr.: Mr. Terman's device for measuring transients should prove a very valuable addition to the instruments for measuring electric conditions which exist for extremely small periods of time. In the Massachusetts Institute of Technology Research Laboratory a good deal of work is being done investigating transient conditions upon smooth artifical transmission lines. If the artificial line, or any line for that matter, is long, the duration of the transient occupies sufficient time to be measured by an oscillograph with a vacuum tube repeater where drawing power would distort the conditions. However, a great many cases arise where short lines with extremely rapid transient oscillations require investigation. Usually the maximum voltage is the point of most interest as one of the chief dangers of transients lies in the rupture of insulation. For this type of investigation the Terman crest meter is ideal. Under those conditions it would also appear possible to use an instrument such as the Compton electrometer instead of the goldleaf electroscope which would somewhat increase the accuracy of the readings providing the transient existed for a long enough time to charge the electrometer.

In Figs. 2 and 3 of Mr. Terman's paper he shows the crest meter connected to an inductance in case *B*. This would not always give the steepness of the wave front, since the penetration of a wave into the inductance depends upon the distributed capacity present. If the inductance were free from distributed capacity then a vertical wave front would be completely reflected and the crest meter would show no reading at all, while the rate of change of current immediately adjacent to the inductance would be really infinite.

F. E. Terman: Intergrity tests of the transient crest voltmeter under severe laboratory conditions have given no indications of a dielectric lag which Mr. Creighton refers to as playing an important part in many vacuum discharges. Considering the mechanism of current flow in a vacuum tube it is evident that the conditions are hardly comparable to those involving a spark. The ever present electrons surrounding the filament begin to move as soon as the electrostatic field is established between filament and plate. This occurs with the velocity of light, making the only lag that arising from the time required by the electron in its travel to the plate, which a short computation shows to be entirely negligible, even for frequencies in the order of many millions.

Certain experimental results verify this reasoning. Thus with the transients referred to in connection with Fig. 8, which were in the order of tens of millions of cycles per second, it was found that when the filament temperature was sufficiently low the electroscope was unable to charge fully on one transient, in contrast with the result accompanying high filament emissions. All evidence obtained pointed to limitations in space charges as the important factor governing speed of operation. Some other experiments not described here, in which travelling waves on a twenty foot pipe were partially reflected by a water column potentiometer gave results for the voltage at the water column which indicated that the crestmeter indications were reliable under these conditions.

Prof. Dellenbaugh points out an important fact that is too frequently overlooked. Where nearly vertical wave fronts exist, reflections, inductance, and minute amounts of distributed capacitance take on exaggerated importance compared with their effects under the more usual conditions. All results given by the crest meter under these conditions must be interpreted accordingly. Where vertical wave fronts are present this is a difficult task, but in the more usual case where the wave front has been rounded off the crest meter is still serviceable.

*A. I. E. E. JOURNAL, Vol. XLII, May, p. 462.

BALANCE METHODS IN ALTERNATING-CURRENT MEASUREMENT*

(BORDEN), NEW YORK, N. Y., FEBRUARY 16, 1923

C. L. Fortescue: This question of Null measurement is one that has been discussed in the Institute in the past quite a good deal. I think that Null methods of calibrating current transformers are in general use now. We ourselves have used a method of calibrating current transformers which was described by me in the Institute JOURNAL some time ago, in which variable mutual inductances were used. At that time we used d'Arsonval portable type galvanometer, and a synchronous contactor. This method was quite satisfactory so long as the contactor was properly maintained; but as we were using this apparatus right on our test floor, with green operators from time to time, who had to be trained to use the device, it was difficult to get them familiar enough with it to be able to tell when it was working properly, and the results were sometimes erratic.

We therefore changed over from the D'Arsonval instrument and synchronous contactor and used instead a dynamometer type instrument, which was excited from a synchronously driven motor-generator set through a phase-shifter. This could be adjusted to give maximum sensitivities for a change in e. m. f. in quadrature to the current or a change of e. m. f. in phase with the current. Thus we had two sensitive positions, and in adjusting our circuit, so as to get zero reading we alternated these two positions making the necessary adjustments until zero reading was obtained.

Now, this hetero-galvanometer or hetero-dynamometer scheme passes through both those positions during the cycle, and instead of getting steady measurement to be reduced to zero, we get slow cyclic measurement to be reduced to zero, so that it amounts to the same thing, but the method used by us is much quicker and simpler to adjust.

However, Mr. Chubb and I made use of this method of a commutator driven at slightly below synchronous speed, a number of years ago, in connection with the calibration of the sphere-gap voltmeter and we found it quite effective. Of course, we were not using it with a Null method, but for direct measurement of crest voltage.

We are using the Null method device which I have described for calibrating current transformers right in our transformer test floor and we have very little trouble now. We are able to detect differences down to a small fraction of a micro-ampere.

I. M. Stein: Mr. Borden has stated that a-c. instruments are of *inherently* lower sensitivity than those for direct current. I believe that the lower sensitivity to which he refers is not inherent but is brought about by the conditions imposed by the use of the instruments. If the conditions are such that an iron-core-electrodynamometer can be used you can obtain as good sensitivity with an a-c. instrument as you can with the best d-c. instruments.

On page 36, Mr. Borden indicates that high sensitivity instruments having permanent magnets are not directly applicable. I do not believe that he intends to exclude the vibration

*A. I. E. E. JOURNAL, 1923, Vol. XLII, January, p. 35.

galvanometer because this instrument is mentioned later on but from the statements made one would be led to believe that vibration galvanometers were not made with permanent magnets. Where the vibration galvanometer is mentioned, the paper states that the vibration galvanometer "is undoubtedly the most sensitive detector" for such work. This is not true because the iron-core electrodynamometer is capable of much greater sensitivity. However, the vibration galvanometer is an excellent instrument for such work and is of particular value in exploring the circuits for stray field effects before starting measurements. In d-c. measurements it is usually satisfactory to shield the measuring instrument from stray fields but in a-c. measurements it is necessary to shield the whole circuit. The fact that the vibration galvanometer responds to all currents of the fundamental frequency regardless of phase relations makes it an ideal instrument for preliminary stray field explorations.

I do not agree with Mr. Borden that the use of the separately excited dynamometer is "slow and cumbersome." That is a matter which depends very largely upon the design of the instrument and its accessories; when properly designed and applied. The use of the separately excited dynamometer is very rapid and convenient.

Referring to the asynchronous commutator and galvanometer to which Mr. Borden has given some new names, I do not believe that the device can be called new. An instrument using this principle and called the "Ondograph" has been in use for more than 10 years. A similar arrangement for measuring a-c. wave form was described in the Institute TRANSACTIONS several years ago. About 3 years ago Mr. Doyle of the Electrical Testing Laboratories described to me a device which he had built and tried out in connection with instrument transformer testing. This device was identical with the one which Mr. Borden describes.

Concerning a-c. opposition methods Mr. Borden has stated that such methods are best exemplified in the Drysdale potentiometer and goes on to say that this instrument is seriously limited in its usefulness. I am afraid that nearly all a-c. measuring instruments are seriously limited but that should not be discouraging. I believe that opposition methods in a-c. work are best exemplified by some of the very useful and convenient methods which have been developed for a specific purpose. I refer to the opposition methods which have been developed for testing instrument transformers. I believe that a mistake is often made in designing an instrument to make too many measurements; accuracy, rapidity and convenience are thereby sacrificed. Concerning the use of the word "Null" I cannot agree with the definition which Mr. Borden has given. A "Null method" is defined in Funk and Wagnall Dictionary as follows:

Null Method: "A method of measurement in which the thing to be observed is not the degree or extent of a thing but merely whether the thing occurs at all, as when the equality of an electrical resistance, with another against which it is balanced, is indicated by the absence of deflection of a galvanometer needle."

I should not consider this source of information a final authority on such matters except that the definition expresses very clearly the generally accepted idea.

There is one point in Mr. Borden's paper which is not brought out as clearly as it deserves to be. This point is in connection with the arrangement shown in Fig. 4. While I do not agree that this arrangement should be called a null method, I believe that the circuit has considerable merit, at least for certain kinds of measurements.

If my interpretation of Fig. 4 is correct, the outstanding advantage of this circuit is that the current in which you are interested can be measured without materially impeding its flow. When the adjustments are made so that a balance obtains, it would appear that the only impedance to the flow of the current is the resistance of the secondary winding.

In measuring small alternating currents, the resistance of this winding would probably be very much lower than the impedance of any instrument winding which you would have to insert in order to obtain the desired sensitivity.

If the circuits in which the current is to be measured were located some distance from where the measurements are to be made, then by placing the ring at the remote point, the impedance of the lead wires between the two locations would be eliminated. Of course, it would be necessary to run four wires instead of two, but in many cases there would be no objection to this, and the elimination of the impedance of the lead wires would be a distinct gain.

H. B. Brooks: Mr. Borden's paper is one of a number of evidences of the great potential usefulness of the potentiometer or balance principle, and it reminds us of the fact, often overlooked, that deflection instruments disturb conditions in the circuit to which they are applied.

In using the two-element wattmeter as suggested by Mr. Borden, it should be kept in mind that the two elements are in general not exactly balanced and that the amount and sign of the unbalance differ from point to point over the scale. For careful work the amount and direction of unbalance at the zero point should be determined, and a suitable correction applied.

Chester L. Dawes: Mr. Borden mentions the Drysdale potentiometer as illustrative of one of the null methods. At Harvard University, we require of each senior electrical engineering student four or five experiments involving the use of this apparatus, and we find it highly satisfactory. It requires perhaps two experiments to give the students skill and confidence in the manipulation of the apparatus. Two, and sometimes three experiments are given in which the students measure the current and voltage relations along artificial lines. As a rule, we use a Campbell bifilar vibration galvanometer as a detector, since it is not affected by stray fields as is the Tinsley magnetic-vane type. I have found that after some practise in the manipulation of the apparatus, balances can be rapidly and accurately made, provided the frequency and voltage are maintained constant. Our power is supplied by a 12 kv-a. alternator, driven by a 20 h. p. d-c. motor. Since we are able to control the field current of either machine from any laboratory, we have little difficulty with variations of frequency or voltage.

I have also used this potentiometer in the investigation of losses occurring in the leads, bus-bars, and adjacent iron supports of large brass furnaces. The potentiometer was set up in a small laboratory adjacent to the furnace room in a large manufacturing establishment. The commercial, 60-cycle power system was used for supply. Currents as high as 5000 amperes were involved, and e. m. fs. of the order of a few millivolts were measured. Balances could usually be obtained rapidly and accurately, even under these commercial conditions. Twice during those times when the main power plant was not in operation, and a small, lightly-loaded, turbo-alternator was carrying the load, some difficulty was experienced in obtaining balances, owing to the slight hunting of the turbine. The fact that the governor was not holding the turbine speed absolutely constant was not appreciated at the power plant until this time.

From my own personal experience, I feel that this type of potentiometer is very useful, and in many cases may be adapted to commercial measurements. Personally, I prefer the simple, vibrating galvanometer to the "heterogalvanometer" method described by Mr. Borden, since the asynchronous contactor adds considerably to the complication of the apparatus.

There is another type of a-c. potentiometer, called the rectangular[1] or two-dimensional potentiometer, which perhaps is not so well known as the Drysdale, because it has not been generally

1. "Alternating-Current, Planevector, Potentiometer Measurements at Telephonic Frequencies," Kennelly & Velander, *Proc. Am. Phil. Soc.*, Vol. 58, April 1919, pp. 97-132.

"A Rectangular-Component, Two-Dimensional, Alternating-Current Potentiometer," Kennelly & Velander, JOURNAL, Franklin Institute, July, 1919.

described in textbooks and engineering literature. A simple diagram is shown in Fig. 1.

R is a non-inductive potentiometer wire, which may be subdivided by any of the various methods employed with d-c. potentiometers. The working current *i* is maintained at its correct value by a rheostat *r*, this current being measured by some type of a-c. milliammeter *A*. This milliammeter is preferably of the dynamometer type, since this type may be calibrated with a standard cell, using reversed d-c. readings. We have also found a vacuum thermocouple, used in conjunction with a d-c. milliammeter, very satisfactory. A hot-wire milliammeter is also satisfactory, if sufficient sensitivity is obtainable. The primary *P* of a mutual inductance *M* is connected in series with *R*. *D* is a detector. The component of the unknown e. m. f., which is in phase with *i*, is balanced along the resistance *R*. The component which is in quadrature with *i* is balanced by an e. m. f. $M\ \omega\ i$ supplied by the secondary of the mutual inductance M ($\omega = 2\ \pi\ f$), where f is the frequency in cycles per second. The unknown e. m. f. is therefore determined as two quadrature components, one along the axis of reals and the other along the axis of imaginaries. By using a reversing switch and positive and negative values of *M*, e. m. fs in any of the four quadrants may be measured. This type of apparatus is simple, does not require a phase-shifter, and may be made of apparatus usually to be found in the measuring-laboratory equipment.

I have found many instances where mutual inductances may be used for making e. m. f. measurements by null methods.

I have also used the separately-excited dynamometer as a detector. Instead of obtaining two balances, one with the

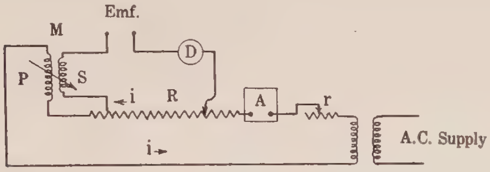

Fig. 1

dynamometer across one phase of a polyphase system, and then across another phase, I have excited the dynamometer from the secondary of a small phase-shifter. In using a separately-excited dynamometer, one or two precautions are necessary. If the moving coil has a metal bobbin, and its plane does not coincide with the direction of the magnetic field, the induced currents in the metal will cause deflection, even though the moving coil is open-circuited. Even with a non-conducting bobbin, this same effect may occur, but to a lesser degree, due to the fact that a current flows in the moving coil windings, because of the capacitance between turns. Therefore, care must be taken when using this type of detector.

I have also used a Drysdale[2] polyphase phase-shifter to supply the current to the Drysdale potentiometer. This phase-shifter does not differ in principle from that described by Mr. Borden. It is more satisfactory than the phase-shifter supplied with the potentiometer, since the rather tedious task of splitting the phase accurately is eliminated, and also it is independent of the frequency.

I have used rotating synchronous contactors of the commutating type, and in one or two cases have experienced difficulty due to frictional electricity being generated. For this reason, I have found that contacts which are opened and closed synchronously by some type of cam are more satisfactory.

I have not as yet had an opportunity to test Mr. Borden's heterodyne methods, and therefore cannot compare them with the methods which I have just described. Undoubtedly when there are slight but continuing fluctuations of voltage and frequency, more rapid balances can be obtained by the heterodyne method.

2. "Electrical Measurements,' F. A. Laws, page 502.

E. D. Doyle: Referring to Mr. Borden's paper (Fig. 8), it would appear to me that this is by no means a null or even a semi-null method. Every instrument there shows a deflection. With regard to the accuracy with which the checking can be done, one has the observational errors in both meters, *A* and *B*, and the only purpose that meter *C* can serve, is to read the difference between *A* and *B* when they are brought to a common indication. Of course, a meter can be held on a point with much greater accuracy than an observation can be made in between the cardinal points.

Referring to Fig. 9, the same observational error comes in as in Fig. 8. However, if the polyphase meter *A* were provided with a very weak suspension, that is, weak compared to the torques of the two elements, you may obtain very great sensitivity. We have applied this particular principle to a double dynamometer of the reflecting type, for comparing a-c. voltages with each other. We have an instrument which we built ourselves, and which enables us to compare a-c. voltages with an error of less than two-hundredths per cent. This is done with a meter which is only consuming about one-fifth of a watt. This particular type of double dynamometer is also available for making comparisons between alternating and direct currents, and may also be used for a number of other purposes, such as measuring an impedance in terms of a pure resistance, by connecting one element first across the resistance and then across the impedance.

Now with regard to detectors, we have had very satisfactory results from a synchronous rectifier and d-c. galvanometer. The rectifier we are now using has brass segments and butt copper brushes. When it is lubricated rather freely with ordinary machine oil we have no trouble at all from thermal e. m. fs., or bad contacts. We have also provided two sets of d-c. brushes, and a double throw switch, we can quickly throw from a position where we are sensitive in-phase voltages, to the reactive position and vice versa thereby making it much more convenient from the operating standpoint.

One other point which I would like to bring up in connection with the various methods of detection is the influence of harmonics in the wave on the particular apparatus. Of course, the vibration galvanometer is sensitive only to the fundamental frequency. The rectifier has a greater sensitivity for fundamental frequency, but any harmonics in the wave, will be detected to a greater or less extent, depending on the phase of rectification, and also on the order of the harmonic.

At a maximum the third harmonic will influence the galvanometer to one-third of its value; because in rectifying two of the loops will balance out, leaving only the third. In a similar way, the fifth harmonic will appear only to one-fifth of its value and so on. The double dynamometer, which has its two elements entirely separate from each other is affected only by the effective value of the wave irrespective of any harmonics which may be present.

P. A. Borden: Both Mr. Fortescue and Mr. Stein have compared the use of the synchronous with the asynchronous dynamometer, the latter gentleman being inclined to differ from my statement that the synchronous use of the instrument was "slow and cumbersome," as compared with the other. I have made many tests using the electrodynamometer in a-c. work, both the indicating type, having about the sensitivity of an ordinary wattmeter, and the reflecting type with a sensitivity comparable to that of a d'Arsonval galvanometer. In these tests I have found I think I may safely say, without exception that the slow swing introduced by asynchronous excitation is much easier to reduce to zero than the two separate deflections necessary where excitation is derived from the same source as the test. This, of course, may lie partly in the accessory equipment used; and I may here say that practically all the apparatus employed in the work described in my paper is that

intended for general use in a laboratory called upon to perform an immense variety rather than a great volume of tests, so that the primary object in the equipment is flexibility rather than specialized fitness for one type of test.

I am pleased to learn that use has been made of the asynchronous commutator in conjunction with a galvanometer. Upon trying this scheme, I was surprised that anything of such evident usefulness had not previously been employed; but being unable to find any published record of its use, by Mr. Fortescue or others, I was forced to refer to my own development of the idea.

Mr. Stein has taken issue with my statement that a-c. instruments are of *inherently* lower sensitivity than direct, and states that if you can use iron in an a-c. instrument you can get the same degree of sensitivity as in a direct. You can, *if you can use iron*; but conditions are unfortunately such that the use of iron is generally out of the question. Again, on reading the context, as it appears in the first paragraph of my paper, I think it will be quite evident that I was here referring to indicating instruments rather than to detectors as used in balance work; and it is a well known fact that even the best makers have not attempted to market a-c. instruments which for smallness of energy consumption could compare with instruments of the permanent-magnet moving-coil type. In the use of an instrument of the electrodynamic type, incorporating iron in its magnetic circuit, my experience is confined to a certain type of a-c. galvanometer, in which I found that before the damping resistance could be reduced to a value to cut out swinging on 25-cycle work, the circulating currents in this circuit, due to e. m. fs. set up in the moving coil completely obliterated the quantities under investigation. In my opinion, it would have been necessary in this case to fit the instrument with a torsion head and make all observations with the moving coil in the position of zero mutual induction with the field.

I think I may be pardoned for having overlooked the Hospitalier Ondograph as an instrument making use of the asynchronous commutator, in view of the fact that the use of that device as a wave tracer is so radically different from my application of the principle as a voltage detector that I had neglected to associate the two ideas. As to the use of the word "Null" in my work, I am quite ready to yield the point to Mr. Stein; and if my usage is not in strict accord with the dictionary definition of the word, admit the fact that I sought no higher authority than the generally accepted technical works and writers. As to whether in the particular instance to which Mr. Stein refers, I have properly classified the test under the heading of "Null," I leave to those interested, to decide. And at the same time I thank Mr. Stein for pointing out the wide uses to which may be put the circuit shown in Fig. 4.

I wish to thank Mr. Brooks for calling attention to the fact that the elements of a polyphase wattmeter may not be in exact balance, at zero or at other points of the scale; and while this was recognized by the writer, it is well to repeat that in tests of this class it is assumed that a high grade instrument is used, in which this unbalance is very small. At the same time; as the deflection of the wattmeter is by the method used reduced to zero, it is usually sufficient that the strengths of the respective elements be equal only at the zero point.

Mr. Doyle has called attention to the possibility of observational errors in the additional meter used in the calibration described in Fig. 8. True, the error of the instrument C, as well as that of A comes in, but in a negligible degree. In the first place, A, the standard is read when indicating on a cardinal point, which is much more definite than the interpolation which would ordinarily be necessary. At the same time, this would usually be a point whereon the accuracy of the standard was determined in comparison with a primary standard. In the second place any error in the calibration of C, appearing as an *error in the error*, would be of the second order of magnitude, and hence usually negligible. The possibility of observational errors, too, is much reduced; for once a setting has been obtained, it may be maintained indefinitely until the tester is assured that the principal meters are in agreement on the point at which the observation is being made. after which he may read the error, as indicated on C, at his leisure. What I have said in regard to observational errors in this test applies equally to Mr. Doyle's comment upon similar errors in the transformer test in Fig. 9, with the additional feature that the wattmeter when finally balanced, is read only upon the zero point of the scale. A two-element meter with a weak spring would, without doubt, greatly increase the sensitivity of this test; but I have found the ordinary type of polyphase instrument, when used on the zero-deflection principle, to have sufficient sensitivity to prove itself of great value in this work.

In demonstrating this method of efficiency determination, I have often made use of a small motor-generator set, driven from a d-c. supply, and giving a single phase output. Such a set has, of course, comparatively large losses; and when the output and input are opposed in a two-element wattmeter, the convenience of the method becomes very evident. This method is particularly useful in determining the efficiency of single-phase rectifiers, and does away with much controversy as to the type of instruments used in the measurement of the rectified output.

MOTIVE POWER IN MEXICO

GOVERNMENT COMMISSION TO ORGANIZE COMMERCIAL EXPLOITATION OF COUNTRY'S NATURAL RESOURCES IN WATER AND FUEL

The Mexican Government according to a report to the Department of Commerce from Trade Commissioner H. B. MacKenzie, has announced the organization of a National Commission of Motive Power, (Comision Nacional de Fuerza Motriz), for the organization, development, planning and supervision of the commercial exploitation of the natural power resources of the Republic. Studies will be made of the legislation in other countries relative to the developments of hyroelectric power, and the generation and sale of electrical energy.

The commission's program includes advising the government which bodies of water should be withheld from power exploitation division of the principal rivers of the country into sections according to their respective possibilities for power or irrigation development; revision of the Federal or local tax laws which may hinder the establishment and operation of hydroelectric plants; study of the advisability of abolishing or modifying the present Federal tax on water concessions; study of the desirability of preserving, restricting or extending the privileges generally granted to power companies; assistance to power companies in obtaining subventions from the government when it is considered that these are for public interest; and the study, in cooperation with local authorities, of the desirability of electrifying certain railroad and street car lines.

It is planned also to exercise control and supervision over hydroelectric plants already functioning with a view to possibly revising the privileges which authorized the establishment of these plants. Similar plans will probably be developed where the energy is generated from sources other than hydraulic.

The Production of Porcelain for Electrical Insulation--V

BY FRANK H. RIDDLE

Champion Porcelain Company, Jeffery-Dewitt Insulator Company

Review of the Subject.—*Forming the plastic clay body into the finished insulator shape prior to the firing to vitrification is of great importance. Among the methods used to accomplish this are:*

1. *Dust or Semi-dry Pressing*
2. *Plastic Forming*
3. *Casting.*

Dust pressed insulators are used chiefly in low-tension work. The prepared plastic body is dried out, dampened with a definite amount of water, pulverized and pressed in steel molds. The density of this product is not so great as that made in other ways, but accurately sized, difficult shapes can be made.

Turning from pugged blanks, throwing and jiggering are processes in which the body is roughly shaped while in the plastic condition, and might be termed "plastic forming." Pieces formed this way are trued up or fettled while still damp but stiff enough to hold their shape.

The most common method of shaping thin-walled insulators is with a hot press die. Here the plaster of paris mold, having the shape of the outside or top of the insulator, is placed on a horizontally revolving wheel, the plastic clay body being placed in the mold and carefully pressed down so as to conform with the mold. A heated metal part is forced down onto the clay in the revolving mold, and shapes the spinning clay into proper form for the bottom of the insulator. The hot metal causes steam to be formed from the water in the plastic clay body, and this acts as a lubricant, preventing the clay from tearing, and also making it possible to form extremely thin petticoats or walls.

Casting is done by preparing the clay body with sufficient water and electrolytes to form a liquid (slip). This is poured into dry plaster of paris molds of proper shape. The plaster absorbs water from the clay, and allows it to stiffen and become firm enough to be handled when the mold is removed after a proper period of time. Properly prepared slip has no more water (hence no more shrinkage) than plastic body. Pouring in the liquid condition makes it possible to form heavy pieces comparatively free from strains.

CONTENTS

FORMING

THERE are several methods of forming the body. The best one to use depends not only upon the working qualities of the body but also upon the character of the finished product. Each method requires a different way of preparing the body, but the various methods need only be mentioned briefly as the previous descriptions of the different operations cover the details.

1. Dry or Semi-Dry Pressed Ware. Filter press cakes are dried out, then broken up into lumps by passing them through coarse rolls. The dry lumps are sprinkled with a definite amount of water (10 to 15 per cent), allowed to stand for 24 hours in a damp room to equalize the moisture content, and finally run through a disintegrator. This machine, which has a rapidly revolving set of hammer-shaped arms, disintegrates the slightly moist body by impact and pulverizes it sufficiently to pass through a 20-mesh screen. It is then in condition that when pressed tightly in the hand it will retain its shape. This "dust" when pressed in metal molds can be made into many complicated shapes, largely used in low-tension work such as switches, fuse plug boards, lamp sockets and the like. In spite of the fact that a high density may be obtained by this process, the pressed mass is lacking in the ultimate cohesion of the particles, so that large amounts of plastic clay and of fluxes must be used.

Turning From Pugged Blanks, Throwing and Jiggering are all executed on the body as prepared by the pug mill.

Casting. There are two general methods for preparing body for casting. In the first method the filter press cakes, while still wet, are placed in a blunger

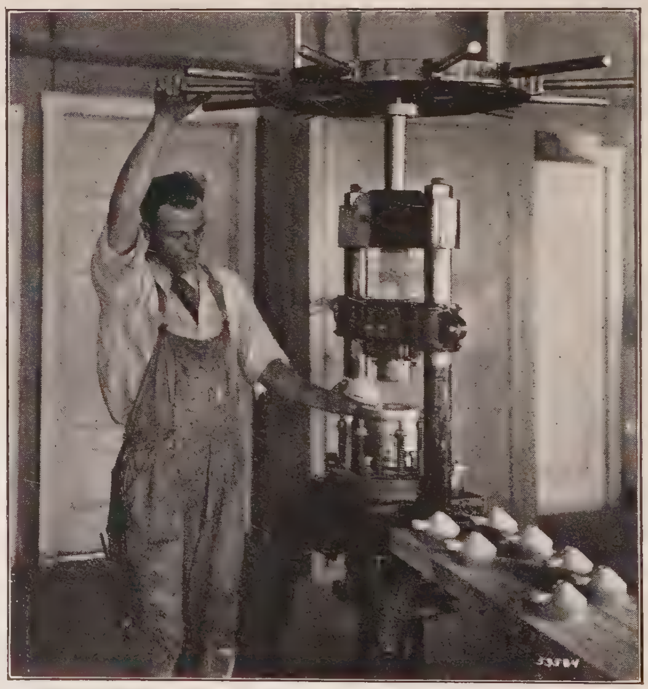

FIG. 21

Dry or semi-dry pressed ware is formed in a heavy screw press. The clay body is prepared in granular form, with just sufficient moisture to make the loose particles adhere to one another when placed under pressure.

with just sufficient water to yield the proper specific gravity of the final slip, together with small amounts

of electrolytes, usually sodium silicate and sodium carbonate. The latter are added to produce a slip having a degree of fluidity which will make it the most workable under the particular conditions desired.

The above method necessitates several extra operations which are eliminated in a second alternate procedure. Here a grinding charge is prepared and ground in the ball mill as usual, and with the clays there are added the electrolytes, so that thorough mixing is obtained. This produces a rather thick, stringy slip, but it is surprising how readily it will pass through a lawn. This slip is then stored in tanks, checked, corrected for specific gravity and fluidity if necessary, and held for use. The first method is preferable for casting exceedingly fine ware with thin walls or where a very high specific gravity is required. The second method should not be employed with blungers, not only on account of the inferior mixing, but also because of the coarseness of the slip, which would necessitate greater care in lawning.

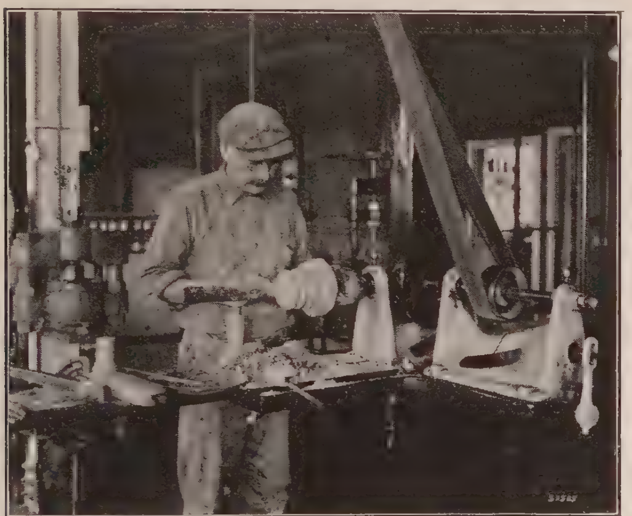

FIG. 22

Turning an insulator from a pugged blank. This blank has been extruded from a die, and after drying sufficiently to be stiff and yet easily whittled, it is placed in a lathe, as illustrated, and shaped with a steel tool while revolving in the chuck.

Casting slip usually has a specific gravity ranging from 1.7 to 1.9 and a fluidity which will permit of easy pouring, but is not great enough to permit the heavier particles to settle out.

The following values apply to some casting slips:

	Max.	Min.
Water Content	35 per cent	30 per cent
Specific Gravity	1.7	1.9
Viscosity	110 seconds	85 seconds
Per Cent Silicates required	0.02 per cent	0.05 per cent

The reason for using electrolytes or salts in casting slips is that they make it possible to produce a mixture in which the water content is exceedingly low, in fact so low that if the salts were not present the mass would not even pour. It is well known that any wet clay body will shrink, the shrinkage varying practically in proportion to the water content. It is obvious, hence, that the lower the water content the lower will be the shrinkage. The importance of this is readily seen when it is realized that severe strains may result from high shrinkage. Where all variables are properly controlled and the shrinkage reduced to the minimum, casting can be done very successfully. Different ways, on account of their different colloidal contents, are affected differently, and it is necessary that great care be taken in the selection of the raw materials which are used.

Turning From Pugged Blanks. There are two methods of doing this, *i. e.*, when the clay is either in the leather hard or dry condition (a water content of 0.7 per cent). For leather hard turning the blanks are partially dried. This used to be done rather crudely in warm rooms, the conditions depending entirely upon the skill of the potter. Modern processing dryers are now used which yield a much more uniform quality of the product. As the blanks at this stage are only partially shrunken, and the degree of shrinking depends upon the degree of dryness, it is evident that lack of uniformity of moisture content will effect the size of the finished product. A piece of clay ware is said to be in the leather hard condition when it is possible to whittle it easily with a knife and still have it stiff enough to retain its shape. When in this condition the piece to be formed can be placed in a lathe and turned in the same manner that wood is turned. If turned by hand considerable skill and time are required. Dry process turning is done by revolving the piece to be turned and facing it with a rapidly revolving grinding wheel. This process is not generally used, as it is controlled by patents. Its advantages are that all the drying shrinkage has been eliminated, all pieces thus being a definite size and only the burning shrinkage left to contend with. The profile of the shape to be made is the reverse of the profile of the grinding wheel and is retained within working limits for a considerable time, which results in great uniformity. The disadvantage of this method is that the excess material ground off is dry dust, the re-use of which presents some unusual and difficult problems, while the shavings from the leather hard turning can be reblunged and worked over if not used in too great a percentage.

Throwing is the most ancient of the forming methods, and is done on a potter's wheel. A lump of thoroughly wedged or uniformly mixed clay of a plastic consistency is placed in the center of the rapidly revolving horizontal wheel and pressed down or centered by hand into a hemisphere very much like forming the hub of a wheel. When thus placed in the center, the piece can be pulled up by hand (drawn) and shaped into the desired form. This method

requires considerable skill and is slow as compared with modern methods.

Jiggering is a development from throwing. Here the wheel consists of a head containing a plaster of paris mold, and is revolved in a horizontal plane.

FIG. 23
The potters wheel. The first operation in the most ancient method of forming pottery by throwing, is known as "centering the ball." This method of forming not only requires great skill, but is not so rapid as more modern methods.

The inside of the mold has the hollowed-out shape the reverse of the outside of the piece to be jiggered. A ball of properly pugged clay is then thrown into this mold and pressed down by hand. The shaping is

FIG. 24
The second operation in throwing is known as the "first draw."

done by pulling down a profile, corresponding to the shape of the inside of the piece, to a position fixed by a guide. The profile cuts off the excess amount of clay in the mold and shapes the piece. This method is very good for thin walled pieces, but in forming thick walled articles there is a tendency to drag. The clay in the mold is revolved with the mold, and as the tool or profile which is stationary is pressed down into this revolving mass it will tend to draw and retard the clay on top while that in contact with the mold is turning. It is necessary to condition the clay so that the chances of a strained structure are reduced to a minimum.

Hot Press Dies are machines which have been developed for electrical porcelain manufacture and are particularly good where it is desired to form thin webs which would tear if made with an ordinary jigger tool. These dies are given the reverse shape of the part to be formed. In the case of an ordinary type of strain insulator made with thin walls, the mold which revolves horizontally would be the shape of the outside or top of the insulator, and the hot press die would correspond to the shape of the bottom,

FIG. 25
Shaping the piece after the final draw. After the ware has dried out sufficiently it is turned and trued up. This method is still used abroad to some extent in the manufacture of insulators.

including not only the thin, high petticoats, but also the threaded center hole in which the pin is fastened. The hot die moves up and down and is heated with a gas flame and kept at such a temperature that when the die is brought down against the clay and mold steam is generated and acts as a lubricant between the die and the clay. It is surprising how thin-walled, high petticoats can be spun by this method.

Casting has been known of and done in a small way for many years; however, it has only been used as a process for forming heavy insulators for the last five or six years. The process of casting consists in pouring the body slip into properly dried plaster of paris molds and allowing the plaster to absorb the water from the slip, leaving the partially dried body hard enough to be handled. When a thin-walled piece is being cast the process is continued until a layer of

proper thickness is formed in the mold, the remaining liquid slip being poured out. The cast piece is then allowed to dry and shrink free of the mold. When heavy solid pieces are cast, as the water is absorbed into the mold, and the slip settles down in the latter

Fig. 26

Jiggering is a semi-mechanical form of throwing. The bottom part of the ware is formed by the plaster mold held in the revolving head. The top is formed by the steel tool which is pushed down into the revolving clay.

Fig. 27

Forming disk insulators by the casting process. Liquid clay body (slip) is poured into plaster of paris molds. As the dry plaster absorbs the water from the slip more slip is poured into keep the mold filled. As the water is absorbed from the slip the body becomes stiff enough to retain its shape, and results in a dense, uniform product.

on account of this displacement, additional slip is added as required until finally sufficient water is removed so that no more settling will take place. The piece will then harden in a solid mass. The conditions of the mold, quality of slip, time of settling, and the temperature of the room are all factors that govern the success of the operation.

In casting a piece like a heavy strain type disk insulator, the molds are filled with slip in the morning, then refilled about three times during the day to replace the water absorbed. The mold is arranged with a collar or reservoir on top to allow an excess of slip to be held each time. The pieces are then allowed to stand over night, a slight amount of steam being turned on to gradually warm the molds and their contents. In the morning the top halves of the molds are removed and the spare or collars cut off the top of the insulators with a thin, fine wire. The pieces are allowed to stand in this condition for another 24 hours to avoid any possible chance of the insulators, while they might still be soft at the cores, from being strained. Slip which has been treated with alkaline electrolytes has the peculiar characteristic that while

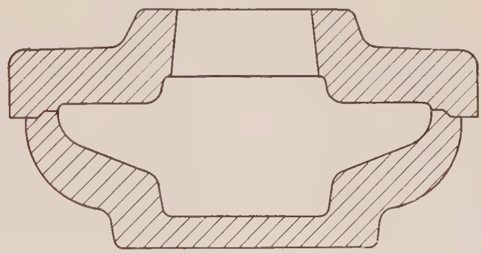

Fig. 28

Cross-section of a high-tension disk insulator mold used for casting.

it may appear to have dried sufficiently to maintain its form, vibration or continued handling will quickly revert it so that it will not only deform but may even become liquid again.

At the expiration of 48 hours, the insulators are removed from the molds and placed on portable racks which are located as near the casting benches as possible, so as to avoid any unnecessary handling. The ware is again held at this point for another 24 hours to be air dried before it is removed to the dryers. In order to obviate any chances of trouble during the air-drying, the entire casting and work room is kept within certain temperature and humidity ranges.

Drying. The drying of clay wares, particularly large, irregularly shaped pieces, is a very important operation, and involves not only a thorough understanding of the piece, but exact control of the drying conditions as well.

Before modern automatic drying equipment had been developed large rooms were used, which were maintained at normal temperatures and as free from air currents and drafts as possible. Many weeks were required to dry large, irregularly shaped pieces. This

of course meant either a small production or else an enormous amount of drying space.

The reason for the difficulty in drying clay wares is, as previously stated, the shrinkage which occurs as the clay body gives up its water. It is obvious that if the evaporation is not uniform, strains are produced which may eventually cause cracks. It is evident that the warmer the place is while drying the more readily it will give up its moisture. But while the piece is being warmed up it tends to dry and shrink on the outside, while the inside is wet and cold. This has been overcome by first subjecting the ware to a treatment in saturated, or at least very humid air, and warming it up under such conditions. The result of this is that the ware will be warmed through uniformly without drying on the surface, since the surrounding air already contains all the moisture it can hold. Additional heat is then applied, not only to heat the clay ware, but also to make the surrounding air capable of carrying more moisture. This results in evaporation of water from the wet clay ware into the air of the dryer. But since the ware has been warmed uniformly the flow of moisture from all parts is uniform. The result is that the drying is done not only at higher temperatures, but more quickly and safely. Where in the past considerable care was used to prevent drafts of all sorts, it has been found that the more completely the air is circulated and the better this circulation bathes all parts of the ware, the more effective and uniform is the drying process. On the other hand, a sluggish draft will expose one side or the top to one condition and the remainder of the piece to another, with the result that the drying proceeds irregularly.

Glazing. Practically all types of insulators are glazed by what is known as the one fire process; *i. e.*, the glaze is applied to the dried, unfired piece. It is then placed in the kiln and fired to maturity. When properly done this is an excellent process, as it not only insures a very close chemical union between the body and the glaze, but it is less expensive than firing twice, as is done with some types of ware such as table ware. In the two fire process there are two methods. The one commonly used in Europe is to first fire to a low temperature, *i. e.* about 950 deg. cent. (1742 deg. fahr.) to 1000 deg. cent. (1832 deg. fahr.), for the purpose of dehydrating the clay or driving off the chemically combined water and hardening the ware so that it may be handled. The articles are then dipped in the glaze and re-fired to the maturing or vitrifying temperature of the porcelain, the glaze being so adjusted that it will mature or brighten at the same temperature at which the body vitrifies. The second method, more commonly used in America, is to mature the bisque in the first fire, then apply a low fusing glaze which will mature at a lower temperature than was used in the first burn. This is the easier of the two processes, and yields a brighter glaze and a higher percentage of grade 1 ware, but the intrinsic quality is not as high as that obtained by the former process, all things considered. The only difference between the one fire and the low bisque, high-glossed process is that the former cannot be used on thin ware such as table ware and the like without causing increased losses. Practically speaking, for heavy ware such as insulators, there is nothing to be gained by using the two-fire method.

There are many different formulas from which glazes are compounded. A brown or "Albany" glaze, suitable for high-tensioned insulators, would have a formula as follows:

Feldspar	3 per cent
Whiting	3 per cent
Albany Slip	94 per cent
	100 per cent

Fig. 29

Forming or finishing room for dressing cast disk insulators. The dry grinding process is used for finishing blanks cast as shown in Figures 27 and 28. After finishing, a coating of glass forming powders known as glaze is sprayed on the surface as shown at the right of the illustration. When fired, the ware is made dense and vitreous, and at the same time the powders melt and forms the glaze.

Add maganese dioxide in a small amount depending on color desired.

The albany slip is used, as it not only fuses to a glass at a lower temperature than that to which the body and glaze are fired, but also because it burns to a beautiful mahogany color. The maganese is added to strengthen this reddish brown color. Other materials not shown here but sometimes used in the glaze with the exception of the whiting or calcium carbonate, which is an active flux in the presence of acids such as silica, are the same as are used in compounding the body, the proportions of flux to refractory, however, being greater in the case of the glaze.

A clear white glaze would have a formula about as follows:

Feldspar	34.0 per cent
Whiting	19.5 per cent
China Clay and Ball Clay	18.7 per cent
Flint	27.8 per cent
	100 per cent

In compounding the glaze there are several important factors to take into consideration. First, the glaze must mature or become a clear glass at the same temperature as that at which the porcelain body matures. Second, and equally important, is that the glaze must fit the body. This means that the coefficient of thermal expansion and contraction of the body and glaze must be such that when the two cool down after the firing, after the body has matured, they will contract at substantially the same rate, so that no strains are produced. After the finished insulator is cooled and later put into use, it is still subject to thermal changes. They are not so great as those produced in cooling the ware in the kiln, but they are not uniform, hence may become more severe. When an insulator is in use, a sudden change in the weather may cause a sudden rise or drop in temperature, which will result in the outside of the insulator, chiefly the glaze, being subjected to an expansion or contraction, thus causing a severe strain. The lower the thermal expansions of the glaze and body are, and the greater the thermal conductivity of the body, the more quickly will the latter be able to absorb and distribute the thermal changes. Low thermal expansion and contraction cause the volume changes to be smaller per degree of temperature change than when the coefficient is greater. High thermal expansion and poor heat conductivity cause the conditions to be very bad. During the past two or three years an understanding of how to control these various conditions better has made possible improvements in the qualities of the various products which are of considerable value.

In the cooling of body and glaze after firing, if the glaze contracts faster than the body the glaze will be in tension when cold. This tension may be great enough to pull the glaze apart into sections or "craze" it. This can crudely be illustrated by comparing it to a mud puddle which is formed in clayey soil and just about to dry up. The skin of mud on the surface, as it dries and shrinks, cracks into many small cakes, leaving spaces between the cakes. This surface might be said to be "crazed".

On the other hand, if the glaze does not shrink or contract as much as the body, the glaze will be under compression when the ware is cold. If, in the final fusion of the glaze on the ware in burning, the glaze has not thoroughly fused, and does not show good cohesion with the body, it will simply shell off the porcelain as the cooling takes place. This is called "shivering". Usually this does not occur excepting in extreme cases, and when the coefficient of thermal expansion of the glaze is slightly less than that of the body.

Quite often expansion or contraction strains exist, but are not sufficient to cause immediate rupture by "crazing" or "shivering". Fracture is sometimes delayed and occurs when the ware is in service. This is often seen on bathroom wall tile and in some cases on table ware, and is much more likely to happen on ware of this sort, which is not vitrified, than in such ware as insulator porcelain. It has been shown that where the body and glaze in insulators are under strain, their strength and resistance to hot and cold tests are not as great as they otherwise would be. This is easily demonstrated by making up tensile test bars of porcelains glazed with various glazes, determining the breaking points of the various specimens and also subjecting similar specimens to heat tests.[1]

It is quite likely that these unbalanced conditions have considerable to do with the failure of insulators, due to time, whether they be in service or in storage.

ELECTRIC SIGNS IN NEW YORK

There are 9577 electric signs in New York, according to a census made recently by the New York Edison Company. These signs advertise every kind of business from undertakers, churches, and bird stores to restaurants and flower shops. Over a million lamps are required to light them. Of these, exactly 947,623 are 10-watt lamps.

This is the first time such a count has ever been taken, and the findings will be valued by the electrical industry to which the number of lights on Broadway will always be of first interest.—*Transactions*, I. E. S.

ARTIFICAL LIGHT TO SAVE COLORS OF TUTANKHAMEN

To preserve the rich trappings of Pharaoh Tutankhamen from fading from their former glory, scientists in London propose that the ancient objects be entirely illuminated with modern artificial light. Recent experiments made in England indicate that museum materials retain their colors longer when electrically lighted than when exposed to any form of nature's daylight.

Daylight contains damaging ultra-violet rays which are not so strong in most artificial lights. The best glass, they say, for use in cutting out these undesirable rays has a distinct yellow color which makes it scarcely practical for exhibiting purposes. Any kind of tinted glass merely delays fading but does not stop it.

Direct sunlight has been known to cause rapid fading, but these scientific experiments indicated that the diffused daylight for which modern museums are designed is six times times as injurious as electric light.—*Transactions*, I. E. S.

1. "The Control of Glaze-Fit by Means of Tensile Test Specimens." *Journal* American Ceramic Society, Vol. 5, No. 8, August 1922. By F. H. Riddle and J. S. Laird.

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

SAVING HUNDREDS OF LIVES A YEAR IN ONE CITY'S TRAFFIC

There are over a million motor vehicles licensed in New York State. Inasmuch as more than 60 per cent of the State's population lives or does business in New York City, handling the traffic problem on the little island of Manhattan is an enormous task.

This dense, ceaseless current of trucks, taxicabs, double-decker busses, motor cars, street cars, and push carts accounted for 36,645 accidents last year, not counting the minor ones that are never reported and placed on the police records.

FIG. 1.—NEW BRONZE TRAFFIC TOWER IN OPERATION AT FIFTH AVENUE AND 42ND STREET

The layout of the streets in New York presents other difficulties to be met. In the early days it was thought that the east and west traffic between the New Jersey and Long Island ferries would far outweight the travel between downtown and Harlem. Accordingly, the cross streets are spaced only 250 feet apart while the longitudinal arteries, the avenues, are on 1000-foot centers. Commissioner R. E. Enright has recently suggested the construction of intermediate overhead avenues which would pass right over the cross streets, and through second-story arcades cut in the big office buildings. Another helpful measure will be the probable eventual abandonment of the present elevated railway structures and their conversion into roadways. New York traffic is growing continuously; traffic problems are consequently becoming more pertinent each year.

The traffic control system of New York is attracting considerable attention as a new field of illuminating engineering. The bronze king-tower of the traffic-directing system, at Forty-Second Street and Fifth Avenue, controls the movement of traffic three miles up and down the Avenue from Washington Arch to 65th Street and all of the cross streets. When red lights gleam from this tower, the traffic officers in the other towers—at 50th, 57th, 38th, 34th, 26th and 14th Streets duplicate the signal, and for sixty seconds all vehicular traffic stops and the pedestrians have the right of way. Immediately after this brief interval, green lights replace the red and east-and-west traffic is released for a minute or a minute and a half. The intermediate or red signal released pedestrian traffic again for sixty seconds, and then the yellow or north-and-south signal, gives a clear road to the Avenue traffic for two minutes.

In emergencies, the time sequence is disregarded by the officer in charge of the king tower. Likewise the tower men on the other crossings, in emergencies, do not guide by the king tower, but they direct the local traffic independently until the situation clears up. When all of the towers work in unison, there is little congestion and few open stretches on the streets; travel proceeds quickly.

Signal tower systems were first provided four years ago. Constant improvements and refinements and the success of the enterprise prompted the Fifth Avenue Association to donate seven bronze towers, costing in the neighborhood of $100,000, to replace those in service. The bronze towers are being installed one at a time.

The New York system decreased serious traffic accidents 12 per cent in the past six months. This decrease is a very potent figure; in both money damages and loss of life, traffic accidents cause more losses in New York City every year than all crimes put together. In death or injury due to vehicular accidents last year 26,890 people suffered; one-half of these were children.

The old signal-tower, replaced at 42nd Street and Fifth Avenue has been erected at Park Avenue and 34th Street. Each of the old Fifth Avenue towers, as it is replaced by one of the new bronze towers presented by the Merchants' Association will be moved to some other strategic location. On Sixth and Third Avenues the standardized green, red, and yellow signal-lights will be mounted on posts on the Elevated Railway structure, and operated from the ground.

JOURNAL OF THE American Institute of Electrical Engineers

PUBLISHED MONTHLY BY THE A. I. E. E.
33 West 39th Street, New York
Under the Direction of the Publication Committee

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Subscription. $10.00 per year to United States, Mexico, Cuba, Porto Rico, Hawaii and the Phillipines; $10.50 to Canada and $11.00 to all other countries. Single copies $1.00. Volumes begin with the January issue.

Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

Pacific Coast Convention

Plans are being matured for the Pacific Coast Convention, which will be held in Del Monte, Calif., October 2-5. The program in tentative form is as follows:

TUESDAY, OCTOBER 2

AFTERNOON
Registration.
Outdoor Recreation.

EVENING
Registration.
Dancing.

WEDNESDAY, OCTOBER 3

FORENOON

Registration.

President Jewett's Address.

President-elect Ryan: Researches Relating to High-Voltage Transmission.

Symposium by Transmission Engineers of the Great West on the Mechanical and Electrical Construction of Modern Power Transmission Lines, including Insulators for High-Voltage Lines.

Mechanical-Electrical Construction of Modern Power Transmission Lines, by C. B. Carlson and W. R. Battey, Southern California Edison Company.

110-Kv. Transmission Line for Oak Grove Development of Portland Ry. Light & Power Co., by H. R. Wakeman and H. W. Lines, Portland Railway, Light & Power Co.

Insulation Design of Anchors and Tower Supports for 110,000-Volt, 4427-ft. Span over Carquinez Straights, by L. J. Corbett, Pacific Gas & Electric Company.

Transmission Line Construction in Crossing Mountain Ranges, by M. T. Crawford, Puget Sound Power & Light Company.

Group Operation of Systems having Different Frequencies. Two papers on this subject by E. R. Stauffacher, Southern California Co. and H. J. Briggs, So. California Edison Co.

AFTERNOON

Symposium by Transmission Engineers of the Great West on Water Wheel Construction, Operation and Governing, etc., by John Harisberger, Puget Sound Power & Light Co. General consideration of the subject.

A Study of Irregularity of Reaction in Francis Turbines, by R. Wilkins, Pacific Gas & Electric Company.

Recent Hydroelectric Developments of the Southern California Edison Co., by H. L. Doolittle, Southern California Edison Co.

Symposium on *The Practise of High-Voltage Switches, Bushings, Lightning Arresters and Busbars; High-Voltage Switches, Bushings, Lightning Arrester Experience of the Southern California Edison Company on its 60,000, 150,000 and 220,000-Volt Systems*, by H. Michener, Southern California Edison Company; *High-Voltage Circuit Breakers*, by A. W. Copley, Westinghouse Electric & Mfg. Co. and *Electromagnetic Forces on Bus Supports*, by L. N. Robinson, Stone and Webster, Seattle.

EVENING

Dancing.

THURSDAY, OCTOBER 4

FORENOON

High-Voltage Insulation, by J. L. R. Hayden and C. P. Steinmetz, General Electric Co., Schenectady.

Power Resources of United States (an illustrated address), by F. G. Baum, Consulting Hydro-Electric Engineer, San Francisco.

Waterwheel Generators and Synchronous Condensers for Long Transmission Lines, by M. W. Smith, Westinghouse Electric & Manufacturing Company.

Performance of Auto Transformers with Tertiaries under Short-Circuit Conditions, by J. Mini, Pacific Gas & Electric Company; L. J. Moore, San Joaquin Light & Power Company; R. Wilkins, Pacific Gas & Electric Company.

Transformers for High-Voltage Systems, by A. W. Copley, Westinghouse Electric & Manufacturing Co.; L. N. Robinson, Stone & Webster, Seattle.

AFTERNOON

Golf Tournament.

17-mile sight-seeing drive in and around Monterey.

Banquet.

EVENING

Presentation of the Edison Medal to Dr. R. A. Millikan followed by an address by Dr. Millikan.

Dancing.

FRIDAY, OCTOBER 5

FORENOON

Carrier-Current Telephony on the High-Voltage Transmission Lines of the Great Western Power Co., by J. A. Koontz, Jr., Great Western Power Company.

Recent Developments in Carrier-Current Communication, by D. L. F. Fuller, General Electric Co.

Some Experiences with a 202-mile Carrier-Current Telephone System, by E. A. Crellin, Pacific Gas & Electric Company;

Symposium on Theory and Practise in High-Voltage Operation, by R. C. Wood, Southern California Edison Company. (An address); A. W. Copley, Westinghouse Electric & Manufacturing Co.

Economic Considerations of Power Factor Control of Long High-Voltage Transmission Lines, by A. V. Joslin, Pacific Gas & Electric Company.

Methods of Voltage Control of Long Transmission Lines by the Use of Synchronous Condenser, by J. A. Koontz, Jr., Great Western Power Company.

Paper on *Telephonic Communication.* (Names of authors later).

AFTERNOON

Recreation, Sports, Sight-seeing.

EVENING

Leave for Post-Convention Trips.

Visit to San Francisco Bay Region Substations, and Big Creek Development of Southern California Edison Company.

The complete program, with details of entertainments and trips, will appear in the September JOURNAL, the Pacific Coast Convention number.

Swampscott Convention Makes New Record

Largest A. I. E. E. Gathering Ever Held—Over 1600 Members and Guests in Attendance—Noteworthy Technical Program Combined with Exceptional Social and Entertainment Features

The 39th Annual Convention of the A. I. E. E., held at Swampscott, Mass., June 25-29, was the largest and probably the most enthusiastic gathering in the history of the Institute. The total registration was 1616, which surpasses by several hundred the attendance at any previous Institute Convention.

The four mornings during the Convention were devoted to six technical sessions, those on two of the days being held in parallel. The interest and the attendance at all of the sessions was notable, the Convention Halls being filled to capacity at most of the sessions.

The afternoons were devoted entirely to entertainments and inspection trips, and the evenings were given over to both professional meetings and lectures, as well as numerous social features. The social and entertainment features were all that could be desired, and on each day of the Convention, from early morning to late at night there were always some activities scheduled for members and guests. The proximity of Swampscott to Boston and Lynn afforded many opportunities for visits to these cities and made the New Ocean House an ideal place for the Convention.

The decoration of the hotel and grounds was novel and unique, including electric illumination, outline illumination, with the latest type of appliqued colors and translucent lighting of towers combined with flood lighting of various kinds. The grounds and verandahs were softly lighted with subdued colored luminaires especially designed for the occasion, which contrasted with the many-colored beams of a battery of searchlights. Numerous festoons of colored flags and pennants were strung from the hotel and brilliantly lighted from concealed sources. There was also a chameleoscopic lighting effect produced by a unit of original design which was of enticing interest—a rich combination of art and illumination, and also the vividaire emblem which added a new and striking feature to the display.

Throughout the decorations of the hotel and grounds, the emblem of the Society and its colors—blue, maroon and gold—predominated in both day and night effects. Every evening of the Convention, a demonstration was made of the giant Mazda incandescent lamp, recently developed. These lamps consume 30,000 watts each and one of them was suspended high above the grounds and afforded an opportunity for all to see the marvellous illuminating effect produced by this largest specimen of its kind.

Too much cannot be said in praise of the work of the local committee, which had charge of all convention arrangements excepting the technical program. Every activity during the Convention was in charge of a subcommittee of the Convention Committee, and all of the subcommittees worked energetically and successfully to see that everyone was satisfactorily entertained.

An Information Bureau was maintained alongside of General Headquarters by members of this Committee, and it functioned so smoothly that the usual confusion incident to large gatherings was eliminated. Everyone in attendance was loud in praise of the Committee's efforts and management, and this praise was well deserved.

The following resolution of appreciation was adopted at the meeting of the Board of Directors of the Institute held during the Annual Convention:

RESOLVED: That the Board of Directors of the American Institute of Electrical Engineers, representing the membership at large and more especially the members and guests in attendance at the Annual Convention at Swampscott, Mass., June 25-29, 1923, hereby expresses its hearty appreciation of the effective services of the local members of the Convention Committee, in making and carrying out with gratifying success the arrangements for the comfort and entertainment of the members and guests of the Institute attending the 1923 Annual Convention.

Among the Committee's activities which was found very useful by everyone in attendance was the publication each morning of a four-paged, daily bulletin, giving the program of the technical, social and entertainment features of the day and various items of news, which put everyone in touch with the day's activities.

The day previous to the official opening of the Convention was given over to a meeting of the Section Delegates, with the officers of the Institute, with the object of discussing the work and policies of Institute Sections. A resumé of these delegate's meetings is given below.

During the afternoon, many of the delegates went on inspection trips to the River Works and West Lynn Works of the General Electric Company, and on automobile trips to Salem, Marblehead and Boston, etc. The evening was devoted to an informal reception and dancing.

Technical Sessions

Tuesday Morning, June 26

The first technical session convened at 10 o'clock in the Convention Hall, and in the absence of Governor Cox, who was unable to be present, the address of welcome was given by Dr. Kennelly, Chairman of the Convention Committee, who, after a short address of welcome, turned the meeting over to President Jewett. President Jewett, called on President-Elect Ryan for a few words, after which he delivered his annual address on "The National Engineering Societies, Their Problems, Past, Present and Future." President Jewett's address will be published in a future issue of the Journal. At the conclusion of this address the technical papers for the first session were presented in abstract by the authors as follows:

Cable Charge and Discharge, by C. P. Steinmetz.

Dielectric Strength Ratio between Alternating and Direct Voltages, by J. L. R. Hayden and W. N. Eddy.

Cable Geometry and the Calculation of Current-Carrying Capacity, by D. M. Simons.

These papers were discussed by Dr. J. B. Whitehead, in a communication read by Mr. Kouwenhoven, J. Slepian, D. E. Howes, D. M. Simons, H. Halperin, H. B. Dwight, R. Notvest, H. N. Davis, C. F. Hansen, with a closure by C. P. Steinmetz.

Wednesday Morning, June 27

The second and third technical sessions were held in parallel on the morning of June 27. The second session was opened by President Jewett, who turned the meeting over to Vice-President R. F. Schuchardt, who took the chair. The first paper, "Some Engineering Features of the Weymouth Power Station" by I. E. Moultrop and Joseph Pope, was called for by the chairman and Mr. Moultrop responded in pointing out some of the special features of the station, after which Mr. Pope presented a somewhat fuller aspect of the paper.

This was followed by written discussions by S. Z. Ferranti and by David Jacobus which were read by Mr. Moultrop. A discussion by Peter Junkersfeld was followed by Prof. Davis, L. L. Elden, H. P. Liversidge and G. L. Knight. The next

two papers on the program, *Cooling of Electric Machines*, by G. E. Luke and *Free and Forced Convection of Heat in Gases and Liquids*, by C. W. Rice, were then abstracted by their authors, after which all three papers were thrown open for general discussion. The speakers were C. J. Fechheimer, W. F. Dawson and H. W. Eales.

The third technical session convened at 10:30 o'clock at the Ball Room of the New Ocean House with President Jewett presiding. After some preliminary announcements President Jewett turned the meeting over to O. B. Blackwell, Chairman of the Telephony and Telegraphy Committee, who assumed the chair. Chairman Blackwell called for abstracts of all of the papers of the morning, which were as follows:

Electric Plant of Transoceanic Radio Telegraphy, by E. F. W. Alexanderson, A. E. Reoch and C. H. Taylor.

Transatlantic Radio Telephony, by H. D. Arnold and L. Espenschied.

Frequency Measurements in Electrical Communication, by J. W. Horton, H. N. Ricker and W. A. Marrison.

Telephone Equipment for Long Cable Circuits, by C. S. Demarest.

Electrical Loud Speakers, by A. Nyman.

After abstracts of all papers had been presented the general discussion ensued, in which the following took part: E. W. Kellogg, A. E. Kennelly, W. H. Martin, S. Haar, J. W. Horton, F. B. Jewett, Gordon F. Hull, W. V. Lavell, Paul G. Andres, with closure by A. Nyman.

Thursday Morning, June 28

GREETINGS FROM DELEGATES OF FOREIGN SOCIETIES

The fourth technical session convened at 10:10 o'clock at Convention Hall, President Jewett presiding. President Jewett announced that the Institute had been honored by having three foreign engineering societies officially appoint delegates to this Convention. The Institution of Electrical Engineers, of Great Britian, Associazione Elettrotecnica Italiana and the Société Francaise des Electriciens. Prof. Elihu Thomson and A. E. Kennelly were the representatives of the English Institution, John W. Lieb and G. Faccioli represented the Italian association and A. LeBlanc represented the French society. Prof. Thomson, Mr. John W. Lieb and M. LeBlanc made brief addresses, expressing the felicitations of their respective societies.

The regular technical program was then resumed, and the following papers were abstracted:

Artificial Transmission Lines with Distributed Constants, by F. S. Dellenbaugh, Jr.

Transmission Line Transients, by V. Bush.

General Considerations of the T and Pi Type Artificial Electric Lines in Connection with a Proposed Compensated Pi Line by H. Nukiyama and K. Okabe (abstracted by A. E. Kennelly).

A Miniature A-C. Transmission System for the Practical Solution of Network and Transmission System Problems, by O. R. Schurig.

Simplified Method of Analyzing Short-Circuit Problems, by R. E. Doherty.

Proximity Effect in Wires and Thin Tubes, by H. B. Dwight.

Floating Neutral, by L. A. Doggett.

These papers were discussed by Aram Boyajian, L. J. Peters, J. Slepian, O. R. Schurig, F. S. Dellenbaugh, Jr., D. C. Jackson, H. W. Buck, Howard L. Melvin, G. N. Armbrust, C. W. Bates, V. Bush, with closures by O. R. Schurig, F. S. Dellenbaugh, Jr. and R. E. Doherty.

Friday, June 29

Parallel sessions were held Friday morning, June 29, which concluded the technical program of the Convention. The fifth technical session convened at 10:00 o'clock, President Jewett presiding. He invited G. H. Stickney, Chairman of the Lighting and Illumination Committee to preside over this session. The chairman called for the presentation of the first two papers on the program, which were *The Quality of Incandescent Lamps*, which was summarized by Mr. Howell and *The Art of Sealing Base Metal through Glass*, by G. W. Houskeeper, who presented his paper in abstract. Discussion on these papers was called for, and was opened by John W. Lieb, followed by Chas. F. Scott, H. Lemp, Jr., C. H. Sharp, A. L. Atherton, with closures by Mr. Howell and Mr. Houskeeper. The last four papers of the session, which were as follows, were then abstracted by their authors:

The Standardization of Electrical Measuring Instruments, by H. B. Brooks.

Pellet Type Oxide Film Lightning Arrester, by N. A. Lougee.

A Continuous-Current Generator for High Voltages, by S. R. Bergman.

Desirable Duplication and Safeguard in the Electrical Equipment of a Generating Station, by W. F. Sims.

The discussion on these papers was participated in by W. B. Kouwenhoven, C. M. Green, A. E. Kennelly, K. B. McEachron, V. E. Goodwin, A. L. Atherton, E. R. Stauffacher, P. L. Alger, H. Lemp, Jr., R. L. Young, J. B. Craighead, followed by closure by the authors.

The sixth technical session, held in parallel with the fifth, was called to order in the Ball Room of the New Ocean House by Chairman F. W. Peek, Jr. of the Electrophysics Committee. The first paper of this session, *Gaseous Ionization in Built-Up Insulation*, by J. B. Whitehead, was abstracted by W. B. Kouwenhoven in the absence of the author. The next paper, *The Axially-Controlled Magnetron*, by A. W. Hull, was abstracted by the author, after which Pres. Jewett assumed the chair and Mr. Peek presented his paper *The Effect of Transient Voltages on Dielectrics*, which was followed by *Two Photographic Methods of Studying High-Voltage Discharges*, by K. B. McEachron. Mr. Peek then resumed the chair and called for discussion of all four papers, which was responded to by H. Goodwin, Jr., C. J. Fechheimer, J. F. Peters, H. B. Martin, J. Slepian, H. J. Ryan, D. D. Clark, D. M. Simons, C. L. Harding, R. B. Williamson, D. E. Howes, H. S. Warren, with closure by K. B. McEachron and F. W. Peek, Jr. This concluded the technical program of the Convention.

Other Business and Social Features

The social and entertainment features provided for the afternoons and evenings during the Convention were unusually numerous and varied in character, including lectures, musical recitals, moving pictures, etc., and dancing was enjoyed until a late hour every evening. On Monday evening after the meeting of section delegates, an informal reception and dance was held at which officers of the local sections and their wives were hosts.

On Tuesday afternoon at 5:30, Professor Karapetoff gave a most entertaining talk on "Relativity," illustrated by a model which served to demonstrate to a remarkable degree some of the conclusions arrived at by calculation. This lecture was found to be so interesting and instructive to both laymen and scientists that it was repeated by request on Friday at the same hour.

President's Reception

The President's reception, on Tuesday evening, was one of the notable events of the convention. President Jewett, President-Elect Ryan, Secretary Hutchinson, and Past Presidents Thomson, Kennelly, Hering, Scott, Jackson, Mershon, Lincoln, Rice, Townley, Berresford and McClellan, many of whom were accompanied by their wives, received the members and guests. Dancing followed the reception and continued until a late hour.

Illustrated Lecture

On Wednesday at 5:30 p. m. Prof. C. E. Magnusson, of Washington University, gave an illustrated talk on the Mountains of the Northwest. The highly artistic colored pictures were appreciated not only for their beauty but they also showed the

Group in Attendance at Past Presidents' Luncheon, Annual Convention, A. I. E. E., Swampscott, Mass., June 28.
Sixteen of the twenty-four living past-presidents, President Jewett, President-elect Ryan, and Secretary Hutchinson were present. All are shown here with the exception of Past-President Buck.
Top row, left to right: Calvert Townley, E. W. Rice, Jr., D. C. Jackson, Charles F. Scott, Paul M. Lincoln. Wm. McClellan, Carl Hering, J. W. Lieb and F. L. Hutchinson.
Bottom row, left to right: A. W. Berresford, Ralph D. Mershon, Harris J. Ryan, T. Commerford Martin, Charles P. Steinmetz. Elihu Thomson, Frank B. Jewett, A. E. Kennelly and C. A. Adams.

almost unlimited capacity of the northwest for hydroelectric development. The Ball Room was filled to capacity during this enjoyable lecture.

Technical Committee Reports

At 8 o'clock Wednesay evening a meeting was called to order by President Jewett for presentation of Technical Committee Reports. These reports were printed in pamphlet form and distributed at the meeting and the presentation by the various chairmen consisted generally in pointing out recent progress in the respective fields, thus bringing the history of the art up to the present time.

Past President's Luncheon

The Past-Presidents' luncheon, held on Thursday, June 28, was one of the most interesting and enjoyable events of the convention. It was attended by sixteen of the twenty-four living Past-Presidents, also by President Jewett, President-elect Ryan, and Secretary Hutchinson. Past-President Elihu Thomson presided; and the names of the other Past-Presidents in attendance are given in the title of the accompanying photograph.

The occasion afforded an opportunity for an informal discussion of various matters relating to Institute activities, including the proposed celebration in some form of the fortieth anniversary of the organization of the Institute, in the spring of 1924.

Musicale

Thursday at 5:30 p. m. Professor Karapetoff gave a piano recital with explanations. Prof. Karapetoff's ability as a musician is well known to all who regularly attend the A. I. E. E. conventions, therefore, it is sufficient to say that the recital was the greatest success from both artistic and instructive viewpoints.

The North Sea Mine Barrage

Thursday at 8:30 p. m. Capt. R. R. Belknap, of the U. S. Navy, gave an illustrated talk on the difficulties, which were encountered and then overcome, first with the design of the mine, then production, and finally the planting of the mine, There seems to be no question that the successful completion of this mine barrage had a distinct influence in bringing the war to a close. The lecture by Capt. Belknap brought home to all present how large a part of the successful ending of the war was due to the fortitude of our sailors in undertaking this most dangerous and difficult task.

Other Novel Entertainments

Unusual entertainment was furnished by the Shoe Style Show, held in the lobby of the hotel Tuesday morning at 9 o'clock. Ten beautiful and stylishly gowned young women, walking upon a raised platform, displayed the latest styles in footwear.

On Wednesday morning at 9 o'clock the Nahant Coast Guard Crew gave an exhibition of life saving on the beach directly in front of the hotel. This crew illustrated the method of rescuing persons from wrecked vessels along the rock bound coast. A large pole representing the mast of a ship was erected on the beach, and the life savers, under the direction of Capt. Gove, shot the line to the mast and showed how the breeches buoy operated, pulling a member of the crew from the mast to safety on the beach.

To the golf enthusiasts the visit of Francis Ouimet was a treat. The green near the hotel was crowded on Thursday morning when this premier in the game of golf entertained the party with exhibitions of many difficult and trick shots. Mr. Ouimet met many of the delegates after the close of this exhibition.

On Wednesday evening "Prisma" colored moving pictures were shown on the lawn of the hotel. The pictures shown were preliminary films, explaining the processes by which the colored and stereoscopic motion pictures were made. A short lecture was given by Mr. W. Z. D. Kelly, describing the latest developments and demonstrating special phases of this new art. This was followed by a 5-reel picture entitled "The Glorious Adventure," which is without doubt the most artistic and beautiful picture ever produced.

The piazzas and walks in front of the hotel were made especially attractive each evening by music received over the public address system from various orchestras in Boston and neighboring towns. This music, in connection with the artistic decorations and special illumination, attracted a wide audience including large numbers of local inhabitants and furnished unique entertainment which will be long remembered.

Inspection Trips and Automobile Drives

Sight seeing and inspection trips were provided in great variety during every day of the Convention. The famous North Shore and Massachusetts Bay with its many beautiful estates and numerous historical places was enjoyed by large numbers of those in attendance. Automobile trips were made daily to Marblehead, Salem, Beverly, Manchester and Gloucester. Visits were also made to Concord and Lexington, the Mecca of all Americans, where was fired "the shot heard around the world." Bunker Hill attracted many visitors, as did the Old North Church and various historical spots in Boston. Harvard University, Radcliffe College, and Massachusetts Institute of Technology also received visiting members and ladies.

There were large numbers of inspection trips made to central stations and manufacturing plants of special engineering interest. These included trips to both of the General Electric Company's Works, the A. M. Creighton Shoe Factory at Lynn, the Massachusetts Avenue Service Buildings of the Boston Edison Company, the Simplex Wire and Cable Company, the Machine-Controlled Exchange of the New England Telephone and Telegraph Company, The Arlington Mills at Lawrence, the Naunkeg Mills at Salem, one of the most up-to-date cotton mills in New England.

An inspection trip was made to the Watertown Arsenal, the largest one in the country, where the visitors were shown through the various laboratories with their equipment for analysis and X-ray work. A demonstration was also given of the electric furnaces which produce steel for the construction of big guns. Another inspection trip of interest was to the Industrial Lighting Company's Exhibition in Boston.

Games

The games and tournaments which have for many years been a feature of the Annual Convention were prominent at the Swampscott meeting. The different contests included golf, tennis, ladies bridge parties, ladies putting contest and baseball.

Golf

The Association was granted the privileges of the Tedesco Country Club which is an exceptionally fine course. The committee arranged four events, conducted as follows:

On Tuesday afternoon, June 26th, Event No. 1 was a kicker's handicap, open to members and guests. The winners were Mr. D. C. Jackson, Mr. Farley Osgood and Mr. R. O. Bentley.

Wednesday, June 27th, Event No. 2 was a four-ball, best ball, medal play, eighteen holes, open to members and guests. Prize for the best gross score was awarded to Mr. L. L. Edgar and Mr. H. P. Hood. Prizes for the best net score were awarded to Mr. H. H. Dewey, Mr. J. B. Sebring, Mr. R. C. Muir, and Mr. S. B. Fortenbaugh.

Thursday, June 28th, Event No. 3 was the Mershon Cup competition, being eighteen holes at handicap medal play. This event was open to members only and was won by Mr. G. L. Knight. The second prize was awarded to Mr. H. W. Eales.

Friday, June 29th, Event No. 4 was arranged as a best selected nine holes out of eighteen holes played, players being allotted one-third of their handicap. This event was won by Messrs. E. H. Everett, Mr. A. A. Brown and Mr. H. R. Summerhayes.

The prize for the winners of each event was one dozen golf balls. In Events No. 1, 2 and 4 there were ties; therefore, the committee divided the prize equally among the winners. In Events No. 1, 2 and 3 there were sixty-seven entries; in Event No. 4 there were forty-two.

Tennis

The handicap tennis tournaments, both singles and doubles, were well patronized, there being 30 teams in singles and 11 teams in the doubles. The singles tournament which carried with it the first win of the Mershon Tennis Trophy Cup, was won by John P. Nikonow, of New York City, after a closely contested five-set match in the finals in which he defeated R. N. Knight.

The doubles event was also won by Mr. Nikonow, paired with Mr. Felix Wunsch, who in the finals defeated D. M. Simons and P. Norton.

Ladies Bridge Games

The Ladies Bridge prize winners at the Convention were as follows: Mrs. Frances Carson, Mrs. N. M. Garland, Miss I. M. Rowlett, Mrs. R. O. Bentley, Mrs. M. K. Bryan, Mrs. W. J. Lloyd, Mrs. H. P. Hood, Mrs. H. B. Logan.

Ladies Putting Contest

The winners of the finals of the Ladies Putting Contest were the following: Mrs. A. K. Warren, Mrs. F. J. Rudd, Mrs. N. M. Garland, Mrs. J. B. Bassett.

Baseball

One of the final events of the Convention was a baseball game on Friday afternoon. This contest between the Watts and the Volts was a classic. The Watts won, 17-2, but chiefly through flukes. The umpire's decisions were as wild as some of the plays, but as he carried a gun and a policeman's "billy," his decisions were not questioned. No record was kept of the line-up, because of the constant changes made.

Section Delegates' Conference

The delegates of the various Sections of the A. I. E. E. met on Monday, June 25, at the New Ocean House, Swampscott, Mass., during the Annual Convention of the Institute, as provided in the constitution for the purpose of discussing Institute activities, particularly those relating to the work of Sections. There were two sessions, one in the morning and one in the afternoon, with an intermission for luncheon. This plan of providing an entire day before the opening of the regular sessions of the convention had been tried last year at the Niagara Falls convention and adopted for the present year upon the recommendation of the delegates themselves, thus enabling them to complete their program and be free to participate in the technical sessions and other events of the convention, which began on Tuesday morning.

The delegates in attendance were:

Section	Delegate
Akron	S. C. Henton
Atlanta	A. M. Schoen
Baltimore	W. B. Kouwenhoven
Boston	W. R. McCann
Chicago	J. E. Kearns
Cincinnati	A. M. Wilson
Cleveland	A. M. MacCutcheon
Columbus	E. Meitz
Connecticut	E. H. Everit

Denver	H. B. Barnes
Detroit-Ann Arbor	E. L. Bailey
Erie	W. J. Seibert
Indianapolis	D. C. Pyke
Ithaca	J. G. Pertsch, Jr.
Kansas City	George C. Shaad
Lehigh Valley	D. M. Petty
Los Angeles	E. R. Stauffacher
Lynn	J. W. West
Madison	H. M. Crothers
Milwaukee	H. W. Cheney
Minnesota	H. W. Meyer
New York	A. E. Waller
Philadelphia	R. B. Mateer
Pittsburgh	M. E. Skinner
Pittsfield	W. P. White
Portland	E. F. Pearson
Providence	R. W. Adams
Rochester	H. J. Schiefer, Jr.
St. Louis	J. M. Chandlee
San Francisco	H. H. Henline
Schenectady	C. M. Davis
Seattle	C. F. Terrell
Spokane	H. L. Melvin
Springfield	C. R. Beardsley
Syracuse	R. D. Whitney
Toledo	P. R. Knapp
Toronto	S. E. M. Henderson
Urbana	H. A. Brown
Washington, D. C.	J. H. Ferry
Worcester	F. J. Adams

Past-President A. W. Berresford, Chairman of the Sections Committee, presided. Others present included President F. B. Jewett, President-elect Harris J. Ryan, Secretary F. L. Hutchinson, and Chairman E. E. F. Creighton of the Meetings and Papers Committee. A number of other present and past officers and officers-elect of the Institute and of the various Sections were also present and participated in the discussions, which were open to all members of the Institute, the only restriction being that the voting was limited to those who had been regularly appointed as delegates of Sections.

Prior to the meeting all of the Sections had been communicated with by the Program Committee, and requested to suggest subjects for discussion at the conference. Later this committee, consisting of Messrs. Harold B. Smith (Chairman), G. G. Post, and D. W. Proebstel, had prepared and issued in advance to all delegates, a program of the topics to be discussed, so that each delegate had an opportunity to ascertain the views of the members of his Section prior to the meeting.

Chairman Berresford called the morning session to order and made a brief statement regarding the purposes of the meeting, and then presented President Jewett, who, in a short address, emphasized the increasing importance of the work of the Sections and referred to the present policy of the Institute of holding four general meetings during the year, and to the fact that a much larger number of high-grade papers are submitted to the Meetings and Papers Committee than can conveniently be presented at four meetings each year. He therefore suggested that it would be necessary to give consideration to having some of the papers presented in future at regular Section meetings, or possibly at regional conventions, rather than to crowd them into conventions at which the time for presentation and discussion is limited. He also called attention to the recent action of the Board of Directors in authorizing a complete re-survey of the technical activities of the Institute, for the purpose of ascertaining what changes, if any, should be made in the scope of these activities and the method of organization of committees or other instrumentalities for carrying on the work.

President-elect Harris J. Ryan was then presented, and in responding, expressed appreciation of the expression of confidence by the membership in electing him to the presidency, to serve during the fortieth anniversary year of the Institute. He called attention to the constantly broadening social effects of the work of the engineering profession, and said: "The electrical engineers have provided their country with universal systems of instantaneous intercommunication and a rapidly growing, soon-to-be-completed universal power network, thereby establishing in abundance mind and muscle that will eventually bring about a far greater and happier nation. Through their Institute they are demonstrating their tolerance of individual differences and a universal capacity to carry-on through those whose homes and business engagements are, in relation to headquarters, near and remote throughout the land. We will ever remember the responsibility thus laid upon us; we will gladly do our best to meet the same effectively."

A general discussion followed, taking up each topic on the prearranged program in order. Some of the principal matters discussed and the actions taken, were:

Interpretation of By-Law 61

At the delegates' conference last year the recommendation was made that by-law 61, which now provides that no action purporting to represent the policy of a Section may be communicated to non-members without authority from the Board of Directors, be modified in order to provide an opportunity for Sections to express their views upon matters of local interest without previous submission to the Board of Directors. A special committee consisting of the chairmen of the Sections and Public Policy Committees, had agreed upon a recommendation that a statement might accompany each official promulgation of the action of a Section, in order to make it clear that said action represents the views of the members of a single Section.

After discussion the delegates recommended that the Board of Directors approve the use of the following statement by Section officers in transmitting to the public press or other non-members, statements of the actions of the Sections:

"As the A. I. E. E. is a national organization, the opinions or recommendations expressed herewith represent only the views of the individual members of the.............Section."

Transfers

It was voted to request the Board of Directors to give consideration to devising some feasible method whereby members in lower grades may be transferred to the higher grades for which they are fully qualified, through the initiative of other members familiar with their professional experience, and without the necessity of the candidates themselves being obliged to submit formal applications for such transfers.

Scope of A. I. E. E. Journal

Chairman Creighton of the Meetings and Papers Committee made a statement regarding the policies that had been followed by his committee in preparing programs of meetings, and also called attention to a plan that has been under consideration for a long time, as a result of the expressed wishes of the membership, whereby highly theoretical and mathematical papers that are probably read by a very limited number of members and others who receive the Journal, shall be published in abstract in the Journal and in full in pamphlet form for distribution to members who desire them, and also in full in the annual Transactions for reference purposes, thus making available more space in the monthly Journal for engineering material of a different nature.

After a general discussion on this subject, the suggested plan was approved and recommended to the Directors.

District Executive Committees

It was voted to recommend to the Board of Directors that at east one meeting be held each year of the executive committee

of each geographical district of the Institute, and that the traveling expenses of the members of the committee be paid.

The executive committee of each district is composed of the vice-president of the district, acting as chairman, and the chairman and the secretary of each Section within the district. Some of the executive committees have already held meetings; and Members of these committees gave direct testimony of the great value of conferences of this nature for the purpose of coordinating the work of the various Sections within each district.

The entire discussion was reported stenographically and an abstract of all the essential features will be prepared and printed in pamphlet form for distribution to the delegates and the officers of all Sections and of the Institute. This pamphlet will also be available to any other members who are interested, upon application to the Secretary at Institute headquarters, in New York.

A. I. E. E. Directors' Meeting

The regular meeting of the Board of Directors of the American Institute of Electrical Engineers was held at the New Ocean House, Swampscott, Mass., on Wednesday, June 27, 1923.

There were present: President Frank B. Jewett, New York; Past-Presidents A. W. Berresford, Milwaukee, and William McClellan, New York; Vice-Presidents H. W. Eales, St. Louis, G. Faccioli, Pittsfield, R. F. Schuchardt, Chicago, W. I. Slichter, New York, F. W. Springer, Minneapolis; Managers E. B. Craft, New York, H. M. Hobart, Schenectady, L. E. Imlay, Niagara Falls, G. L. Knight, Brooklyn, N. Y., A. G. Pierce, Pittsburgh, Harlan A. Pratt, Hoboken, N. J., R. B. Williamson, Milwaukee; Secretary F. L. Hutchinson, New York. Also present, by invitation: Officers-elect Harris J. Ryan, Stanford University, Calif., W. F. James, Philadelphia, H. P. Charlesworth, New York, William M. McConahey, Pittsburgh, W. K. Vanderpoel, Newark, N. J.; and Past-President Calvert Townley, of New York.

A report was presented of a meeting of the Board of Examiners held June 15 and the actions taken at that meeting were approved. The following action was taken upon pending applications: 94 Students were ordered enrolled; 278 applicants were admitted to the grade of Associate; 14 applicants were elected to the grade of Member; 2 applicants were elected to the grade of Fellow; 24 applicants were transferred to the grade of Member; 2 applicants were transferred to the grade of Fellow.

Approval by the Finance Committee of monthly bills amounting to \$23,156.62 was ratified.

The Secretary reported 1047 members delinquent in the payment of dues for the fiscal year ending April 30, 1923; and the Board directed that the usual efforts be continued to collect these dues, through the Secretary's office and by bringing the lists to the attention of the Section officers concerned.

In accordance with a request of the Philadelphia Section, the Board unamiously voted that the Midwinter Convention next year be held in Philadelphia, in either January or February 1924, exact dates to be decided later.

A report was presented from the secretaries of the four Founder Societies, outlining and recommending a plan for a cooperative employment service, as referred to elsewhere in this issue; and the Board approved the recommendations contained therein.

A communication was presented from the Director of the Engineering Societies Library, outlining a plan for establishing a loan collection of books, on a basis which it is hoped will ultimately make the service self-supporting, a nominal charge to be made per day for each book loaned; and the Board endorsed the plan.

In acceptance of an invitation from the President of the Society for the Promotion of Engineering Education, the President was authorized to appoint two representatives to act as counselors to confer with a Board of Investigation and Coordination to be created by the S. P. E. E. for the purpose of supervising and directing an extended and intensive study of engineering education.

A motion was unanimously adopted expressing the hearty appreciation of the Board of the effective services of President Jewett during his administration. President Jewett responded, expressing his great pleasure at having been associated with the members of the Board during the year now drawing to a close.

A resolution was adopted expressing appreciation of the effective services of the local members of the Annual Convention Committee, "in making and carrying out with gratifying success the arrangements for the comfort and entertainment of the members and guests of the Institute attending the 1923 Annual Convention."

Reference to other matters discussed may be found in this and future issues of the JOURNAL under suitable headings.

1922 Transactions

After the distribution of copies of the above volume to those members who subscribed in accordance with terms announced by the Board of Directors of the Institute, there remains a limited surplus from which additional subscriptions may be filled.

The TRANSACTIONS comprise those technical papers, discussions and reports presented before meetings of the Institute or otherwise which have been deemed worthy of permanent record by the Institute. The discussions of technical papers have in each case been printed in conjunction with the paper. The volume is bound in the standard green cloth, 9 in. by 12 in. size.

The subscription price to members of the Institute is \$2.00, shipping cost prepaid. If it is your intention to maintain a file of this publication, it is desirable that your subscription shall be received immediately. As stated above, the surplus of this edition is limited and subscriptions will be filled in the order in which they are received at Institute headquarters.

STANDING ORDER FOR TRANSACTIONS

Provision can be made for standing orders to send copies of each edition of the TRANSACTIONS to be published hereafter and for which the subscription price does not exceed \$2.00.

Your subscription to the TRANSACTIONS, and remittance covering same, should be addressed to American Institute of Electrical Engineers, 33 West Thirty-ninth Street, New York, N. Y.

Addresses Wanted

A list of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street.

1.—M. G. Bindler, 2 Margaret St., Derby, Eng.
2.—F. G. Burka, 10 Roulo Ave., W. Fort St. Sta., Detroit, Mich.
3.—Harold B. Clymer, 26 Klein Ave., Trenton, N. J.
4.—R. A. Harman, c/o Tar Heel Mica Co., Plumtree, N. C.
5.—Howard W. Key, 506 W. 32nd St., Austin, Texas.
6.—Edwin C. Miller, 968 Morris Ave., Bronx, New York, N. Y.
7.—P. B. Munro, 462 Sherbrooke St., Peterboro, Ont.
8.—Richard T. Quaas, 2154 Crotona Ave, New York, N. Y.
9.—V. K. Srinivasaiyengar, No. 554-6 Malleswaram, Bangalore, India.
10.—Lester E. Tunison, Pickwick Hotel, 833 So. Grand Ave., Los Angeles, Calif.

Engineering Societies Employment Service. The New "Cooperative Plan"

While it has been generally recognized that the Employment Service, conducted as a joint activity of the four national societies of Civil, Mining, Mechanical and Electrical Engineers constitutes one of the most valuable activities of these societies and is far more efficient in its present status than when handled as an independent service by each society, the maintenance expense to the societies has been heavy. Also the scope of the service and its value to the individual member and the employer very evidently falls short of what might be possible under a more comprehensive plan of operation were larger funds available. A joint committee to study the service was appointed in November 1922, consisting of two representatives from each of the four societies as follows: American Society of Civil Engineers, J. P. Perry, E. S. Nethercut; American Institute of Mining & Metallurgical Engineers, F. T. Rubidge, J. V. W. Reynders; American Society of Mechanical Engineers, Prof. J. W. Roe, E. W. Swartwout; American Institute of Electrical Engineers, Prof. W. I. Slichter, H. C. Carpenter.

This Committee elected Prof. Slichter as chairman. All phases of the service were studied and on March 17, 1923, the Committee submitted a report to the governing bodies of their respective societies. The following conclusions of the Committee were unanimously reached:

1. That during the year 1922 the present Engineering Employment Service filled 2604 positions at a cost each of $6.62. Some form of employment service either in the form of cooperative action or by each of the individual societies should continue to be maintained.
2. That it is desirable to work out a plan which would be a cooperative activity available to the four National Societies, and
3. That such a service should be national in scope.
4. That the service should be available only to the members of the four national societies, and to the members of such other societies as may be invited by them to cooperate.
5. That there should be no charge to employers.

The Committee recommended that the scope and service rendered be enlarged, but it being impractical to meet the increased expense of such development from the present income of the societies, they suggested arranging a service to be partly supported by those who use it. They also recommended

"That the free keyed advertising of positions available for employers and the privilege at present accorded members of promiscuously replying to the same, and the posting of Positions Available in the position books now available in the offices of the Service, the Societies and the Library be discontinued."

As representing some of the interesting factors which guided and influenced the Committee in arriving at their conclusions, the following paragraphs are quoted:

" . . . that out of a total of 5347 members of the four national societies who registered and attempted to use the service 2931, or 56 per cent actually secured jobs. The detailed figures by each society are as follows:

"A. S. C. E.—48 per cent of those attempting to use the Service secured jobs.

A. I. M. E.—31 per cent of those attempting to use the Service secured jobs.

A. S. M. E.—52 per cent of those attempting to use the Service secured jobs.

A. I. E. E.—61 per cent of those attempting to use the Service secured jobs.

"The seriousness of the situation may be better appreciated when it is realized that many have been unemployed from six months to nearly two years. A large proportion of those still seeking employment are members of ten or more years experience.

"During the four years, 1919 to 1922,—5035 engineers who were not members of any of the four societies, but who were introduced by members, were permitted to use the service. Of this number, 1558 secured positions. Since October 1, 1922, the service has been denied to non-members, a considerable number of whom have applied for membership.

"Volunteer committees have functioned as an emergency means in different parts of the country soliciting inquiries for the service, and advising that the service is free to employers. In New York City alone, over two hundred members of the four national Engineering Societies made over 13,000 personal calls of which over 8000 interviews with executives resulted and nearly 1000 positions uncovered. Along with this they distributed announcement cards bearing the insignia of the four societies in the corners of same with printed matter.

"That the welfare of the societies is believed to depend in a large measure upon the personal helpfulness which it extends the individual members. The Employment Service is a considerable factor when considered from the standpoint of membership. Especially is this true with respect to the younger membership of the societies, and the recent graduates in engineering. It is estimated that between 80 per cent and 90 per cent of the membership of the societies represent the employe class even though a considerable number are employers as well.

"Cooperation saves time, effort and expense in a movement like this and broadens opportunities for the membership and the profession. It also permits of a closer contact between employers and applicants when carried into a national plan through regional or sectional offices. An analysis of placements and registrations by states throughout the country shows that nearly every inquiry for service outside of the Metropolitan district has been filled. Obviously if more inquiries came to the service from outside of the Metropolitan district, more of the members residing in remote places could be better served. Placements and registrations bear a fairly uniform proportion irrespective of geographical location. The larger a selective employment service the better the results to both employers and employes and to the profession by getting the right man in the right place."

The Secretaries of the A. S. C. E., A. I. M. E., A. S. M. E. and A. I. E. E., under whose supervision the Employment Service has been conducted, have prepared a plan in which they have endeavored to solve the various problems, formulated in the report of the Joint Committee, with definite recommendations as to method of organization, financing and procedure. This report has been accepted by the governing bodies of the four societies. The plan as recommended will be put into operation beginning September 1st. The report in full follows:

To the Governing Bodies of the
A. S. C. E., A. I. M. E., A. S. M. E. and A. I. E. E.

Gentlemen:

Subject: Proposed "Cooperative Employment Plan" restricted to members and with a limited free service.

A careful analysis of the various reports previously made on the employment service rendered by the four societies named above to their members for many years past, combined with a further study of the whole question of employment service, emphasized the desirability of continuing some form of service to the membership of these societies.

It is generally recognized, however, that the funds which are available from the treasuries of the four societies have not been, and are not likely to be, sufficient to establish and conduct an adequate service of national scope.

Free Service: It is the unanimous opinion of the undersigned that while continuing free service to a limited extent, principally

by the publication without charge of announcements of available men in the respective journals of the societies concerned, in addition to this there should be put into effect a plan looking toward a national employment service that will be partially supported by those who are directly benefited by the service. Each society through its Secretary and staff will continue, as in the past, to assist members in a confidential and personal manner to new positions giving, obviously without charge, advice as to opportunities known to the Secretary and so far as possible the Secretary, also as formerly, will go further in writing letters of introduction, etc., to assist members to possible openings and conversely in important positions to assist employers. It can however be only to a limited extent as is obvious.

The excellent report submitted to the four national societies of Civil, Mining, Mechanical and Electrical Engineers under date of March 17, 1923 by the joint committee of these four societies which was appointed to study the whole question of employment service, formulated very definitely the problems involved in rendering employment service by professional engineering societies; and it is the purpose of the present report to endeavor to solve these problems by submitting a plan with definite recommendations as to method of organization, financing and procedure.

It has not been thought desirable that the societies should withdraw abruptly from the support of the joint bureau, on the one hand, nor that they should continue full support as in the past. It is proposed that jointly the societies contribute say, one half the amount appropriated in the past, and that the balance be obtained from fees from those benefited; in other words a Cooperative Service.

However, during the introductory period it will be necessary to underwrite the bureau, but according to the estimates it does not seem probable that the bureau will fail to bring in the necessary fifty per cent of the cost. To provide against possible shrinkage the societies are asked jointly to underwrite the full amount, but at a basis prorated according to the placements made last year; *i. e.*, according to the following table:

	Placements	Appropriation Requested	Amount Underwritten
A. S. M. E.....	1150	$4130	$8260
A. S. C. E......	505	1815	3630
A. I. E. E......	450	1635	3270
A. I. M. E......	120	420	840
Total......		$8000	$16000

Cooperative Service: We recommend that the present arrangement be continued until September, and that commencing on September first a "maintenance charge" be made to all those who obtain positions through the efforts of the Employment Service, on a basis mentioned below, and which it is estimated will eventually provide for employing and developing a personnel adequate to render satisfactory service, with proper investigation of all positions available and a careful *individual* handling of all applicants for positions. The staff should include eventually competent investigators who, as soon as information is received regarding a vacancy, should visit the prospective employer and obtain complete data regarding the requirements of the position. The Service would then be in a position intelligently to select the proper candidates. These investigators should also be used to inquire into the qualifications of all those who register for positions, either by personal calls on the last one or two employers of the applicant, or otherwise—not for the purpose of checking up the character of the applicants, as the service we recommend is to be limited to members of the four societies only—but for the purpose of completing the analysis of the applicant's training and experience, and thereby improving the judgment of the Employment Management in selecting "the right man for the job." A further development would be to have these investigators keep in personal contact with the larger employers of engineering talent, and through personal calls develop new channels for service, also as occasion offers, to develop new opportunities for the engineering profession in positions now held by non-engineers.

We wish to emphasize here that the problems confronting the employment service to be rendered by these professional societies are peculiar to themselves, and cannot be solved by methods which may have proved advantageous to commercial agencies; neither would the practises employed in personnel departments of the larger industries be acceptable to the average member of any of these societies. What the member requires when he is seeking a position is special sympathetic and confidential consideration, and painstaking investigation of the requirements of the position.

In order to give the greatest satisfaction it must be possible to pay a great deal more attention in the future to developing methods of obtaining knowledge of opportunities for engineers through the services of investigators as referred to above and otherwise. In the past it has not been possible, because of lack of funds, to do nearly as much in this direction as should be done. It is, of course, not possible for an employment service to create positions, and in times of industrial depression there will always be many more available men than positions; but even during the severe depression beginning about two years ago, active work by members of volunteer committees of unemployed engineers resulted in the finding of a large number of positions.

Therefore, without repeating the details relating to the history of the service previously rendered, or the conditions to be met, all of which are adequately covered by the report of the joint committee referred to above, we recommend the adoption of the following

Plan for Employment Service for the Members of the A. S. C. E., A. I. M. E., A. S. M. E. and A. I. E. E.

(1) That the four societies continue their support of the employment service for their membership, to be conducted as heretofore under the supervision of an executive board made up of the four secretaries thereof.

(2) The publication of notices of men available to be continued in the societies' journals without charge to members, thus providing for a continuance of free service to members.

(3) That beginning September 1, 1923, a "maintenance charge" be made to all those who obtain positions through the Employment Service, on the following basis for the first year, with such adjustments later as may be deemed necessary:

$10 for all positions paying a salary of $2000 per annum or less.

$10 plus one per cent of all salary in excess of $2000.

Temporary positions: one month or less, 3 per cent of amount of salary received and no refund of Bulletin subscription.

Thus, for example, the fee for a $2000 position would be $10
" " " " 2500 " " " 15
" " " " 5000 " " " 40

(The average of salaries paid for positions filled through the Employment Bureau during the last ten months has been over $3000; and approximately 2500 positions have been filled during the past year). Based upon conservative figures, the estimated income for twelve months would be

1500 × $20 = $30,000

(4) That registration of available men be restricted to members of the four societies named above, at least until the plan has proved to be entirely satisfactory and financially sound. Later the question of extending the Service to members of all organizations exchanging courtesies with these four societies could be considered, including state, county, or local engineering organizations with which any of the local Sections of the four national societies are affiliated; to members of the student engineering organizations affiliated with these four societies.

(5) That beginning with the inauguration of the paid Service, the publication of "Positions Available" in the societies'

journals be discontinued. In its stead there should be substituted an employment bulletin, which will be sent out at suitable intervals only to those who are regularly registered as available. (It is estimated that about one-third of the present 3600 on the registration list would be desirous of having their names continued thereon, and would be agreeable to paying a registration maintenance fee on the following basis: Three months, $3; one year $10; thus making a fund of approximately $3600 available every three months for the purpose of publishing the bulletin. This should be sufficient to support a weekly issue distributed under first class postage. Positions would be listed with a key and credit would be made on the "maintenance charge" of the amount paid for the current quarter of the employment bulletin, or for advance quarters.)

(6) That whatever surplus remains at the end of the first year from the income from fees and the amount appropriated by the societies, be utilized for the extension of the Service to other cities; this plan to be continued from year to year until the Service is developed to a truly national basis; if necessary the "maintenance fees" to be increased sufficiently to provide funds for this widening of the scope of the activity—as the narrowness of the present Service is its chief weakness. (Whereas in the larger cities the work might require not only the entire time of one man, but also of some assistants, in smaller cities it will probably be possible to arrange with local engineering organizations to divide the time of one man between the Employment Service and the Secretaryship of a local society.)

(7) That the four societies agree to underwrite this Service for one year, on the basis of the cost of maintaining the present Service for the past year, apportioned according to the number of members of each society who obtained positions during the last year and actually appropriate fifty per cent of the amount underwritten; the appropriation to be made available for use at any time during the year.

The undersigned are hopeful that all four governing bodies of the national societies concerned will give prompt approval to these recommendations in order that the plan may be promptly announced in our publications and put into effect on September first.

In conclusion we call attention to the fact that the joint committee whose report was recently submitted was advised by legal counsel that a paid Service limited to the members of the societies only, such as recommended herein, could be inaugurated without involving the question of taxation, and without requiring compliance with the laws relating to employment agencies. However, even if this should not prove to be the case, our recommendations still stand, as the amount involved for taxation of the office space to be utilized and the employment licensing fees would not be sufficient to jeopardize our proposed plan.

Respectfully submitted,

John H. Dunlap, Secretary, A. S. C. E.
F. F. Sharpless, Secretary, A. I. M. E.
Calvin W. Rice, Secretary, A. S. M. E.
F. L. Hutchinson, Secretary, A. I. E. E.

Philadelphia Section Prepares for Active Year

The Philadelphia Section is preparing under the direction of Chairman-elect Ross B. Mateer for a very active year. New activities are to be inaugurated such as presentation of latest developments in the industry at stated meetings,—selling the aims and activities of the Institute to students,—coordination of relations with other Sections. The finance committee has prepared a definite budget for the year. The following is a list of committees appointed with their chairmen: Finance, J. L. MacBurney; Meetings and Papers, R. B. Mateer, ex-officio; Membership, P. E. Tillson; Publicity, E. C. Drew; Attendance, L. H. Rittenhouse; Technical, H. S. Phelps; Student Branch Activities, C. D. Fawcett; Sections Coordination, L. J. Costa.

Core Losses in Electrical Machinery

The National Research Council, in its division of engineering, has appointed a committee on Core Losses in Electrical Machinery. This committee has in course of preparation, with a view to publication, a bibliography, or list of publications on the general subject of core losses, from 1885 to 1922, including eddy currents, skin-effect and hysteresis, as well as their effects on the behavior of electrical machinery. In view of the great industrial and technical importance of core losses on the output, efficiency, heating and cost of electrical machinery and apparatus, it is very desirable that the subject should be thoroughly studied, so as to reduce such losses to a minimum.

All persons interested in the subject and especially in the preparation of a useful bibliography, are invited to communicate with the Secretary of the Committee, Mr. P. L. Alger, Induction-Motor Department, General Electric Company, Schenectady, N. Y.

FEDERATED AMERICAN ENGINEERING SOCIETY

ENGINEERS PROTEST AGAINST REMOVAL OF DIRECTORS OF THE U. S. RECLAMATION SERVICE

Engineers are protesting strongly against the removal of Arthur P. Davis as Director of the U. S. Reclamation Service. Secretary Work's action is characterized as prejudicial to the public interest, and the Secretary is described as pursuing a dangerous course.

The Federated American Engineering Societies have raised formal and vigorous objection to the displacement of Director Davis. The position of the Federation is explained in the following statement by Executive Secretary L. W. Wallace:

"The Federated American Engineering Societies has a membership of 28 engineering societies. They are local, state and national in scope and have headquarters in 24 cities of the United States. The combined membership of these 28 societies is 50,000 engineers. The engineers represented through the 28 societies formed the Federated American Engineering Societies in order that they might have an agency through which to give expression to the views of engineers regarding public questions of an engineering aspect.

"The sole purpose for which the organization was formed is that of enabling engineers of the United States to render an essential public service. Its reports on 'Waste in Industry' and 'The Twelve-Hour Shift in American Industry' are expressions of the way in which the organization has been functioning in the interest of the public. It has also functioned in relation to certain national legislation and activities of Governmental bureaus, all of which has been done for the sole purpose of being of service to the American public.

"The recent change made in the Director of the Reclamation Service, therefore, comes within the purview of this organization and many other engineering and technical groups. The officers of the Federated American Engineering Societies, as well as the officers and members of many engineering and technical groups, are much concerned with the recent announcement relative to the displacement of the Director of the Reclamation Service and appointing in his stead a man who apparently is not technically trained and fitted to direct an important technical service of the Government.

"This procedure is looked upon with grave concern by the engineers and technical men of the United States, because such summary action as discharging an eminently successful employe after 35 years of service without a hearing or adequate explanation, and with a request to hand in his resgination to take effect within two weeks will undermine the morale of all the technical agencies of the Government and may lead the most competent men to more readily accept engagements with commercial

and industrial agencies, thus interfering with the efficient operation of the technical bureaus of the Government.

"If it is true, as has been reported, that certain governmental officials believe that a man not technically trained and fitted is more competent to direct a technical bureau than one so trained is correct, then, indeed such action as has taken place regarding the Reclamation Service might be reasonably expected to occur in other technical branches of the service, such as the Bureau of Mines, the Bureau of Standards and the Geological Survey as examples.

"Members of engineering and technical bodies are not willing to believe that such policy is a wise one and is in the best interest of the American people. Many technical directors of large works both within and without the Government Service, have ably directed such projects both from a business point of view, as well as from a technical one.

"One of the marked tendencies in recent years has been the placing of technical men in charge of large industries and commercial enterprises. The managing directors or presidents of many large public utility companies, railways and industrial organizations are technically trained men. Therefore, the step taken in connection with the Reclamation Service is contrary to the policy of many industrial organizations.

"Because of the far-reaching results that might ensue and because of the seriousness of the situation, the organized engineers and technical men of the United States are preparing to make a thorough search into the considerations that led to the action taken in regard to the Reclamation Service. The American Society of Civil Engineers has appointed a special committee to investigate the matter. The Public Affairs Committee of the Federated American Engineering Societies, through its chairman, J. Parke Channing of New York, has already addressed a letter of inquiry to the Secretary of the Interior concerning the action.

"This is being done not from the standpoint of questioning the right of a Government official to discharge anyone that he may elect, but from the point of view of the wisdom of the announced policy that a technical bureau can be more effectively directed by a man not technically trained and fitted in comparison with one so technically trained and fitted.

"The work of the Reclamation Service is essentially engineering and technical. There are business aspects to be true, but so far as known there has been no criticism of the business direction of the Service, other than perhaps by certain interests in the West which have endeavored to secure a reduction in or have endeavored to repudiate payments for reclaimed lands purchased.

"Should this demand prevail, the fundamental principle of the enabling act will be displaced and the revolving fund for the continuation of the work will be dissipated, so that other needed projects cannot be carried out unless there be additional drains upon the Treasury of the United States. Furthermore, should such an eventuality ensue public confidence in the integrity of the direction of such work would be so shaken as to make it difficult to secure appropriations from Congress to extend the work of reclaiming the arid lands of the west.

"In the main, the support for such has come from the West, but should there be a question as to the wisdom with which the projects are selected and executed then it is entirely probable that the West would not receive support from other sections of the country. Therefore, not only is the morale of the technical service at issue but also the larger thing, perhaps reclamation itself.

"It is these considerations that are causing organized engineers and technical men to make a thorough study of the situation. Undoubtedly pronouncements will be forthcoming as the result of such study. The evident interest and concern among engineers and technical men regarding this situation, as well as their views, may be gleaned from the strong editorials that have and are appearing in the technical publications regarding it."

ENGINEERING FOUNDATION

REPORT FOR THE YEAR ENDED FEBRUARY 8, 1923

The Annual Report for the eighth year of the work of the Engineering Foundation has recently been published. This report includes a general resumé of the year's work, by Chairman Alfred D. Flinn, financial statement, a list of Officers and Members of the Board and Committees for 1922 and 1923, and a list of publications. "Graphitic Corrosion of Cast Iron," by J. Vipond Davies, and "Internal Stresses in Metals," by E. P. Polushkin appear in the appendix. The Second Report on the Research on the Fatigue of Metals, which has been carried on by H. F. Moore and T. M. Jasper at the Engineering Experiment Station of the University of Illinois, is printed at the end of the book.

American Engineering Standards Committee

OVERHEAD LINE MATERIAL SPECIFICATIONS CONSIDERED BY A. E. S. C.

The American Electric Railway Association has submitted its specifications for overhead line material for action by the American Engineering Standards Committee, to determine the question of sponsorship and to arrange for the submission of the specifications already developed by the A. E. R. A. to a duly organized sectional or working committee, which will make such revisions and additions as may be necessary to bring these specifications up to the full status of an "American Standard." The special committee to consider the question of sponsorship and scope of the specifications, which are also of direct interest to other than electric railway interests, is headed by Mr. A. H. Moore, representing the Electrical Manufacturers Council on the A. E. S. C., and includes representation from the National Electric Light Association, American Railway Association, Electrical Manufacturers Council, American Institute of Electrical Engineers, American Electric Railway Association, American Short Line Railway Association, and the Bell Telephone System.

The attitude of the A. E. R. A. in submitting its specifications for this action by the A. E. S. C. will very definitely favor the unification and elimination of conflicting specifications in this field, which is a very important one to a large group of industries, and involves expenditures of great magnitude annually in construction, maintenance and replacement of power, light, telephone, telegraph and railway signal lines.

44th Meeting American Electrochemical Society in Dayton

The Fall meeting of the American Electrochemical Society September 27-29 gives promise of being one of the most interesting sessions ever held by this Society. The papers and discussions will be of particular interest to electrical men, chemists, foundry men and electroplaters.

Dayton, Ohio, has been chosen as the place of meeting with headquarters at the Miami Hotel. The technical meeting will be devoted to a symposium on "Electrochemistry of Gaseous Conduction." Mr. Duncan MacRae of the Research Depart-

ment of the Westinghouse Electric & Manufacturing Company will act as Chairman. This session will include a number of most interesting papers and discussions on triatomic hydrogen, ozone, X-ray tubes, audions, neon lamps, Beck Arc, oxidation of atmospheric nitrogen, etc. A number of very interesting papers are in the course of preparation by men who are well qualified to discuss these respective subjects.

The other subject of the symposium covers "Recent Developments in Electrolytic Refining of Metals." Mr. F. R. Pyne of the U. S. Metals Refining Co., Carteret, N. J., will act as chairman. This program will embody papers on copper, tin, lead, nickel, zinc, iron, etc.

An innovation of this meeting will be a Round Table discussion on the following four subjects: Electric Furnace Brass Foundry Practise, Utilization of Chlorine, Organic Electrochemistry, and Electroplating. These Round Table discussions will be presided over by men recognized as authorities on these particular subjects, and will be of special interest to men in this locality, because many brass foundries are located in Dayton and the main phases of the brass melting art will be discussed. Dayton is also one of the largest and most important electroplating centers on account of the large amount of electroplating carried on by companies such as the National Cash Register Co.

Convention of Illuminating Engineering Society

The 1923 Convention of the Illuminating Engineering Society is to be held September 24 to 28 inclusive at Lake George, N. Y.

A unique program of entertainment is being provided and unusual spectacular lighting features are being planned. It is hoped to combine business and pleasure at this Convention in a manner to enable all visiting delegates, and particularly the ladies, to enjoy the wealth of scenic beauty so abundant in this wonderful country of mountains and lakes.

A well balanced program of commercial and technical papers is being prepared by the Committee on Papers under the direction of Mr. J. L. Stair of Chicago. The officers of the General Convention Committee are:

Messrs. W. D'A. Ryan, Chairman, H. W. Peck, Vice-Chairman, H. E. Mahan, Secretary, all of Schenectady, N. Y.

National Officers of I. E. S. Elected

The newly elected officers of the Council of the Illuminating Engineering Society for the fiscal year 1923-1924 are as follows:

President, Clarence L. Law; General Secretary, Samuel G. Hibben; Treasurer, L. B. Marks; Vice-President, D. McFarlan Moore; Directors: James P. Hanlan, Howard Lyon and H. F. Wallace.

PERSONAL MENTION

A. M. Jacobs, after a stay of three years in the Far East, has returned to his native country and has joined the staff of the Electricity Supply Commission of the Union of South Africa.

Robert T. Anderson has resigned as an instructor in Electrical Engineering at the University of Pennsylvania to accept a position as Chief Engineer at Girard College.

James Masek has severed his connection with the Cutler Hammer Mfg. Company of Milwaukee and is now associated with the Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

A. M. Talbot, formerly with the Ohio Public Service Company in Cleveland, has been appointed General Manager of the Tremont Gas, Electric Light & Power Co., operating in Tremont, Nebraska.

C. L. Fortescue has recently been appointed manager of the newly-created Porcelain Insulator and Transmission Engineering Department of the Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

E. J. Steinberg resigned on June 1st as Resident Engineer for the Railroad Commission of Wisconsin, and has accepted a position as Service Engineer with the Milwaukee Electric Railway and Light Company.

James P. Bradner, who has been connected with one of the government departments at Washington, D. C., has been placed in charge of the Pacific Coast Sales division of the Pyrene Manufacturing Co., in San Francisco, Cal.

Anna C. Hoegen and Harry D. Garretson, Associates of the A. I. E. E., were married on June 11, 1923. Mrs. Garretson is a technician of radiotherapy and Mr. Garretson is Secretary and Treasurer of Waite & Bartlett Mfg. Co.

E. M. Kerr has left the employ of Mr. P. H. Reardon of San Francisco, where he designed special machinery for use in canneries, and is at present with the Pacific Gas & Electric Company in their Northern California territory.

Emerson Pugh has resigned his position as Instructor in Electrical Engineering at Purdue University to enter the Development Engineering Division of the Western Electric Company at Chicago.

Lester W. Scheu has left the employ of the Hickok Electrical Instrument Company, Cleveland, Ohio, to accept a position with the Price Electric Company, where he is in charge of their laboratory.

George W. Vaughan, formerly Assistant Professor of Electrical Engineering, Trinity College, Durham, N. C., is now connected with the Electric Bond & Share Company, in its Electrical Division.

Frank B. Carpenter, formerly Electrical Engineer with the West Virginia Engineering Company, Charleston, W. Va., has severed his connection with that firm and is now Electrical Engineer, in charge of the Electrical Department, of the J. C. Sullivan Mining Interests of West Virginia.

Philip S. Beigler has given up his position as Associate Professor of Electrical Engineering at the State College of Washington to become head of the Department of Mechanical and Electrical Engineering at the University of Southern California, at Los Angeles.

Joyce R. Kelly has severed his connection with the Telephone Sales Department, Western Electric Company, to take up the work of engineering consultant in the Research Division of the Policyholders Service Bureau, Metropolitan Life Insurance Company, New York City.

Chas. L. Leighton has recently resigned as Manager of the Cushing, Oklahoma, property of the Minnesota Electric Light & Power Company and has accepted the position of Manager of the Commercial Department with the Fort Smith Light and Traction Company, at Forth Smith, Arkansas.

Addams S. McAllister, who has during the past two years been liaison officer of the Bureau of Standards and the Federal Specifications Board, assigned to the headquarters of the American Engineering Standards Committee in New York City, has been recalled to Washington for special work by Secretary Hoover of the Department of Commerce.

N. H. Coit has resigned his position as Superintendent of the Auburn Plant of the Western Public Service Company, Auburn, Nebraska, to take up duties as Assistant to H. G. Harvey, Commercial Manager of the Pennsylvania Edison Company, Easton, Pa. This latter Company is one of the important links in the Pennsylvania-New Jersey Power System controlled and operated by The W. S. Barstow Management Association, Incorporated.

Obituary

Captain Robert W. Hunt head of the firm of Robert W. Hunt & Co., consulting engineers, died at his home in Chicago on July 11th. Captain Hunt who was very well known to the steel trade was recently the recipient of the Washington Award, the presentation taking place at the annual meeting of the Western Society of Engineers on June 18, 1923. This 1922 award was made to Captain Hunt "for preeminent service in promoting the public welfare, for his pioneer work in the development of the steel industry in the United States and for a life devoted to the advancement of the engineering profession." Robert W. Hunt was born in Fallsington, Pa., December 9, 1838. In 1857 he moved to Pottsville where he spent several years acquiring a practical knowledge of steel mill operation and chemistry. He later established the first analytical laboratory maintained by an iron and steel company in America. In 1865 he introduced the use of the cupola for remelting. He superintended the rolling of the first steel rails produced on a commercial order in America. In 1873 he became superintendent of the Bessemer plant at Troy, N. Y. In 1883 Mr. Hunt was elected President of the American Institute of Mining Engineers, and in 1891 President of the Mechanical Engineers. In 1906 he was again President of the A. I. M. E. and in 1893 President of the Western Society of Engineers. In 1912, the John Fritz Medal was awarded to Mr. Hunt "for his contributions to the early development of the Bessemer process."

Past Section and Branch Meetings

PAST SECTION MEETINGS

Akron.—June 5, 1923. Election of officers as follows: P. C. Jones, Chairman; C. D. Black, Secretary-Treasurer. There was a paper by S. H. Mortensen of the Allis-Chalmers Co. on "Synchronous Motors in Rubber Mill Service." This was a joint meeting with the A. S. M. E. Attendance 95.

Denver.—June 8, 1923. Annual meeting and election of officers as follows: H. B. Dwight, Chairman; W. C. Duvall, Vice Chairman; R. B. Bonney, Secretary-Treasurer. The speaker of the evening was W. W. Lewis, of the General Electric Company, who spoke on "Some Problems Pertaining to the Interconnection of High-Tension Power Systems." The lecture was illustrated by moving pictures. Attendance 45.

Lynn.—May 11, 1923. Subject: "The Measurement of Sound." Speaker: A. G. Webster, Professor of Physics, Clark University. Attendance 110.

June 25, 1923. Annual meeting. The following officers were elected: L. E. Smith, Chairman; C. A. B. Halverson, Vice Chairman; P. E. Twiss, Secretary-Treasurer. Attendance 105.

Madison.—June 5, 1923. Election of the following officers: Geo. E. Wagner, Chairman; J. E. Wise, Member of Executive Comm. E. J. Kallevang, of the Wisconsin Power, Light & Heat Co. spoke on "Transmission Systems of Wisconsin." Attendance 17.

Milwaukee.—Feb. 20, 1923. Subject: "Cross Flow Impulse Turbine." Speaker: Forrester Negler, of the Allis-Chalmers Mfg. Co. Attendance 225.

March 22, 1923. Subject: "Brine Spray Information." Speaker: S. C. Bloom. Attendance 200.

April 18, 1923. Meeting held under the auspices of the Engineers Society of Milwaukee, at which George F. Staal spoke on "The Destruction Plant at Montevideo." Attendance 175.

May 16, 1923. Meeting held under the auspices of the A. S. C. E. at which Mr. Harrington, National President of the A. S. C. E. addressed the audience on "Civic Responsibilities of the Engineer." Attendance 250.

May 28, 1923. This was a dinner meeting for members of the Section and student members at Marquette University and School of Engineering of Milwaukee. A social program was arranged, and the principal speakers were George Andrae, John I. Beggs and John McDill Fox. Attendance 103.

Philadelphia.—June 19, 1923. Election of officers: Ross B. Mateer, Chairman; R. H. Silbert, Secretary; E. C. Drew, Asst. Secretary. This was field day for the local sections of A. S. M. E. and A. I. E. E., and golf, tennis and baseball were enjoyed, after which there was a dinner.

Pittsburgh.—June 21, 1923. As officers for the ensuing year the following were elected: Ollie Needham, Chairman; M. E. Skinner, Secretary. R. A. Manwaring, of Dwight P. Robinson & Co. gave an illustrated lecture on "Accomplishments of American Engineers in Brazil." Attendance 50.

Toledo.—June 15, 1923. Subject: "History of the Toledo Edison Plant." Speaker: T. J. Nolan. An inspection of this plant followed the speech. Attendance 35.

Urbana.—May 16, 1923. Election of officers as follows: Ellery B. Paine, Chairman; Chas. T. Knipp, Secretary and Treasurer. Attendance 8.

Vancouver.—June 5, 1923. Election of officers as follows: F. W. MacNeill, Chairman; Asger Vilstrup, Secretary. Attendance 9.

PAST BRANCH MEETINGS

University of Arkansas.—May 1, 1923. Subjects: "Methods of Radio Control," by H. M. McCain; "Uses of Radio," by Dean Ault; "Descriptions of Some Radio Stations," by L. G. Lovell. Attendance 11.

May 15, 1923. Engineers' Annual Camping and Inspection Trips.

May 29, 1923. Election of officers as follows: Joe Cunningham, Chairman; L. G. Lovell, Vice Chairman; C. E. Bowman, Secretary; Joe Blake, Treasurer. Descriptions were given by three students of plants visited on inspection trips. Attendance 14.

Marquette University.—June 5, 1923. Election of officers as follows: E. O. Triggs, Chairman; Wm. A. McCarville, Vice Chairman; N. Hoffman, Secretary, W. J. Hecker, Treasurer. Attendance 28.

University of Michigan.—April 26, 1923. A talk on the history of some old machines in the Engineering Laboratory was given by Dean Patterson. Attendance 40.

University of Washington.—June 5, 1923. Election of officers: Edward Kraft, Chairman; Edwin T. Naden, Secretary. T. M. Libby, of the Todd Ship Yards at Tacoma, gave a talk on "Electrical Communications on Naval Ships." Attendance 24.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

BOOK NOTICES (JUNE 1-30, 1923)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

DICTIONARY OF APPLIED PHYSICS, V. 4; LIGHT, SOUND, RADIOLOGY.

By Richard Glazebrook. Lond., Macmillan & Co., 1923. 914 pp., illus., diagrs., tables, 9 x 6 in., cloth. 63s.

Volume four of the Dictionary follows the plan of its predecessors, that is, it defines briefly the minor terms in its field and refers the user for further information to the extended articles by experts on general topics. These general articles are well-rounded summaries of present knowledge on the principal topics, provided with adequate references to the literature.

In this volume the subjects discussed are sound, light and radiology. Special articles are included on crystallography, diffraction gratings, the eye, glass, goniometry, graticules, infra-red transmission, interferometers, the kinematograph, lenses, light, luminous compounds, the microscope, navigational instruments, opthalmic apparatus, optical calculations, optical glass, periscopes, photographic apparatus, photometry, the pianoforte, polarimetry, polarized light, projection apparatus, the quantum theory, radiation, radioactivity, radiology, radium, range-finders, shutters, sound, sound ranging, spectrophotometry, spectroscopes, spherometry, surveying instruments, telescopes, and wave-length measurements, as well as on other subjects.

APPLIED MECHANICS.

By Alfred P. Poorman. 2d edition. N. Y., & Lond., McGraw-Hill Book Co., 1923. 293 pp., diagrs., 9 x 6 in., cloth. $2.75.

A text-book for undergraduate courses in engineering schools. Departs from the usual procedure by making extended use of the graphic method of solution and by presenting a large number of illustrative examples which have been solved in detail to show the relation between the principle which has been developed and the problems to which it applies. Several changes have been made in the new edition and the section on statics has been expanded.

APPLIED PERSONNEL PROCEDURE.

By Frank E. Weakly. N. Y., & Lond., McGraw-Hill Book Co., 1923. 192 pp., 8 x 6 in., cloth. $2.00.

This book is not intended to be an exhaustive treatise on personnel administration, but rather to describe in concrete fashion a number of phases of personnel management with which the work of the author has made him familiar. He writes from long experience as a worker, as head of a personnel department and as a general executive. The methods that he describes will fit both large and small organizations and have been tested by use.

BUREAU OF NAVIGATION. By Lloyd M. Short.

FEDERAL POWER COMMISSION. By Milton Conover.

(Institute for Government Research. Service monographs of the U. S. Government, Nos. 15 and 17). Balt., Johns Hopkins Press, 1923. 9 x 6 in., cloth. $1.00 each.

Like the other volumes of this series of studies of the services of the United States government, these monographs on the Bureau of Navigation and the Federal Power Commission are designed to give an account of their history, organization and operations. Of use to the public, members of Congress and executive officers. The plan of the books is uniform. They give in each case a history of the establishment and development of the service, a detailed description of its activities, an account of its organization and of its plant, a compilation of the laws and regulations governing its activities, financial statements showing its appropriations and expenditures, and a full bibliography of the sources of information.

DIESEL AND OIL ENGINE HAND BOOK.

By Julius Rosbloom. Los Angeles, Technical Publishing Co., 1923. 376 pp., illus., diagrs., tables, 7 x 5 in., boards. $3.00.

The first five chapters of this handbook explain the principles of the Diesel engine, describe the pumps, governors and other auxiliary machinery and give directions for testing. Chapter six offers detailed descriptions of a number of commercial types, and chapter seven discusses Diesel-electric ship propulsion. The book is intended as a reference work for practical men.

THE DYNAMO, ITS THEORY, DESIGN AND MANUFACTURE. Vol. 2.

By C. C. Hawkins. 6th edition. N. Y., & Lond., Isaac Pitman & Sons, 1923. 322 pp., illus., diagrs., 9 x 6 in., cloth. 15s.

In the opening chapter of this volume, which completes the study of continuous-current dynamos, a detailed analysis of the effect of armature reaction on the flux-curve under load is given both for non-commutating-pole and commutating-pole machines. Succeeding chapters discuss commutation and sparking at the brushes, the heating of dynamos, dynamo design, working and management. Two designs are worked out in full, to illustrate the application of the numerous formulas which have been given in the text.

ELECTRIC MOTORS; Vol. 2, Polyphase Current.

By Henry M. Hobart. 3d edition. Lond., & N. Y., Isaac Pitman & Sons, 1923. 384 pp., diagrs. 9 x 6 in., cloth. $4.50.

Volume one of this treatise was reviewed recently. The concluding volume continues the account without interruption, giving special consideration to polyphase current questions. The treatise is intended for the designer rather than for the student and is intended to show the state of the art at the present time.

ELEKTRISCHE DURCHBRUCHFELDSTARKE VON CASEN.

By W. O. Schumann. Berlin, Julius Springer, 1923. 246 pp., diagrs., tables, 10 x 7 in., paper. $1.40.

Presents the results of the author's experimental investigations and the theories to which these have led, together with a summary of the work of previous investigators.

The book is divided into three sections. The first summarizes, briefly but completely, all published measurements of discharge potentials and breakdown fields. Section two contains an introduction on the kinetic theory of gases, followed by an account of J. S. Townsend's work on the phenomena of spontaneous discharge in gases. The section closes with an attempt to picture the state of the conducting bodies in gases in strong fields which is necessary for sparking. In the third section the considerations of section two are applied to atmospheric air, the dependence of the electric strength upon the geometric arrangement of the electrodes being especially studied.

ELEKTRISCHE SCHALTVORGANGE.

By Reinhold Rüdenberg. Berlin, Julius Springer, 1923. 504 pp., illus., diagrs., 9 x 6 in., boards. $4.00.

A book discussing the changes of a temporary nature which may occur in electric circuits and which are of interest in the operation of high power electric systems. Treats both the phenomena produced intentionally in the transition to a new operating state and those of an accidental character which are accompanied by short-circuit and over-voltage phenomena. The work is based on a series of lectures delivered by the author, the Chief Electrician of the Simens-Schuckert Works, before the Electrical Engineering Society of Berlin, but the lectures have been expanded to cover the results of all recent investigations. A bibliography is included.

JAHRBUCH DER ELEKTROTECHNIK . . . . . 1921.

By Karl Strecker. Munchen, R. Oldenbourg, 1923. 237 pp., 10 x 7 in., paper. $1.00.

The *Jahrbuch der Electrotechnik* is an annual report on the more important results and occurrences in electricity, prepared by specialists from a review of the book and periodical literature. The present volume corresponds to the calendar year 1921. The book is classified into four main classes, Electro-mechanics, Electrochemistry, Communication and Signalling, and Measurements and Scientific Research, which are further divided into specific subjects, each of which is surveyed by a specialist. About 140 periodicals, chiefly German, have been reviewed.

LIGHTING CIRCUITS AND SWITCHES.

By Terrell Croft. N. Y., & Lond., McGraw-Hill Book Co., 1923. 472 pp., illus., diagrs., 8 x 6 in., cloth. $3.00.

Prepared for use as a practical reference book, this work discusses those circuits and connections, and their applications, which are needed at times by everyone concerned with electric lighting. Although the simpler circuits have been included, the chief emphasis is placed on the more complicated circuits and control methods.

The material relates almost wholly to electric lighting circuits and switches for interior applications, operating on low-potential systems. Most of it concerns 110-220-volt, two-wire or three-wire systems. One chapter is devoted to theater lighting circuits. The text is concise, the information being chiefly set forth by diagrams and drawings.

MOLECULAR PHYSICS.

By James Arnold Crowther. Ed. 3. Phila., P. Blakiston's Son & Co., 1923. (Text-books of chemical research and engineering). 189 pp., illus., diagrs., tables, 8 x 5 in., cloth. $2.50.

The three years that have elapsed since the second edition of this book have been marked by great changes in scientific thought. The nuclear theory of the atom has been placed on an incontrovertible basis and our knowledge of the structure and constitution of the atom has been thereby immensely increased. In order to reflect this new outlook as faithfully as possible the whole text of the book has been thoroughly revised, and rewritten where necessary. A new chapter on the theory of quanta and its extension to atomic phenomena has been added. The new edition, like its predecessors, is a coherent, intelligible account of the present state of the electrical theory of matter.

RAILROAD ELECTRIFICATION AND THE ELECTRIC LOCOMOTIVE.

By Arthur J. Manson. N. Y., Simmons-Boardman Publishing Co., 1923. 332 pp., illus., diagrs., tables, 9 x 6 in., cloth. $4.00.

A book written to give railway officials and operating men a knowledge of the design, construction and operation of electric locomotives and of their application to different kinds of railroad service. The book opens with a statement of theoretical principles, which is followed by descriptions of the various motors and other elements of the electric locomotive, illustrated by examples from practise. Examples of the solution of problems encountered in electrification are given. An appendix contains a brief history of the electrification of American steam railroads and a number of useful tables covering electrification projects throughout the world.

SCIENTIFIC MANAGEMENT AND THE ENGINEERING SITUATION.

By Sir William Ashley. Lond., Humphrey-Milford, Oxford University Press, 1922. (Barnett House Papers, No. 7). 28 pp., 9 x 6 in., paper. $.35.

This pamphlet contains the Sidney Ball Memorial Lecture delivered before the University of Oxford, 28 October, 1922, by the Vice-Principal of the University of Birmingham. Sir William Ashley devotes himself to criticism of Scientific Management, particularly as applied to engineering and the metal trades. His examination is analytical and his attention is particularly directed toward the method of remuneration of labor. He finds much to criticize unfavorably from the viewpoint of the student of economics, in present theories of management, and indicates his objections briefly in an interesting way.

Employment Service Bulletin

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

MEN AVAILABLE.—Under this heading brief announcements will be published without charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL should be addressed ***EMPLOYMENT SERVICE, 33 West 39th Street, New York, N. Y.,*** *the employment clearing house of the National Societies of Civil, Mechanical, Mining and Electrical Engineers.*

Notices for the JOURNAL are not acknowledged by personal letter, but if received prior to the 16th of the month will appear in the issue of the following month.

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case and forwarded to ***EMPLOYMENT SERVICE,*** *as above.*

Replies received by the bureau after the position to which they refer has been filled will not be forwarded, and will be held by the bureau for one month only.

OPPORTUNITIES

Instructors (2) in the Department of Physics. 1-2 years experience, to conduct recitation and class work in undergraduate courses. Applicant should have had some graduate study or experience in electrical measurements. Application by letters. Salary not stated. Location, New York City. R-1101.

Instructor in electricity. Equivalent of High School education. Eight years' practical experience including apprenticeship time 50 per cent of time spent in technical school allowed. Experience of journeyman electrician or foreman, who has worked with the tools for the required period, but while doing so has acquired sufficient knowledge of the related theory and drawing to train boys to the point where they are not only intelligent employes, but also productively efficient. Application by letter. Salary not stated. Location, Mass. R-1095.

POWER SALES ENGINEER for progressive central station in excellent field. Application by letter. Salary not stated. Location, New England. R-1402.

SALES ENGINEERS, young single men for positions as sales and service engineers, calling on superintendents, managers, engineers, chemists, and metallurgists, for manufacturers of well-known high-grade automatic electrical and temperature equipment, extensively used in factories, power plants, chemical and industrial works. Knowledge of physics and elementary electricity required. Graduates of technical schools preferred. Candidates must be free to travel in the great manufacturing and industrial districts. Young men of good address and ability to talk

convincingly to engineers wanted, but no previous experience demanded. Write describing education, earning experience, if any, and stating age, salary desired. Location, New York City. R-1406.

EXPERIENCED DIE DESIGNER with technical knowledge and practical experience in the drawing and stamping of metals. Must be competent to take charge of entire design on small parts of a complicated nature. Must have manufacturing ability in addition to engineering and designing experience. Application by letter. Salary not stated. Location, Michigan. R-1414.

ELECTRIC DISTRIBUTION ENGINEER, with experience in over head lines. Application by letter. Salary not stated. Location, Central America. R-1421.

MECHANICAL ENGINEER with operating and maintenance experience in large industries. Man between 30-40 years of age. Application by letter. Salary not stated. Location, New York State. R-1426.

MECHANICAL ENGINEER, 30-40 years, having had foundry and machine shop experience to act as assistant to general manager of a wire mill machinery company in coordinating the work of the different departments. Application by letter. Salary not stated. Location, Illinois. R-1450.

MAN to take charge of Transformer Assembly Dept. Must thoroughly understand high-voltage apparatus and the assembly of such apparatus in large units. Application by letter. Salary not stated. Location, Canada. R-1451.

MECHANICAL ENGINEER. American between 27-40 years of age, pleasing appearance and personality, the ability and experience to write and prepare a concise report on diversified engineering projects, and at least 5 years' experience in practical estimating work. Application by letter. Salary not stated. Location, N. J. R-1453.

PUMP TESTER WANTED. Man having experience in the testing of centrifugal pumps, steam pumps, and power pumps. Must be thoroughly familiar with modern test floor methods and competent to handle electrical and hydraulic equipment. Application by letter stating age, experience, present salary and salary expected. Location, Michigan. R-1475.

SUPERINTENDENT for a cement plant, having a capacity of about 250 barrels per day. Must be able to take entire charge of plant and capable of checking up chemical analysis of cement when necessary. Application by letter. Salary not stated. Location, Peru. R-1476.

GRADUATE ELECTRICAL ENGINEER having had considerable experience on power house and industrial building design work, capable of layout of power and light circuits, switchboard and wiring diagrams of generating units, calculation and layout of power feeders, calculation of illuminating systems and making up material lists. Application by letter. Salary not stated. Location, New York City. R-1478.

OPPORTUNITY for ENGINEERS, responsible executive, preferably familiar with manufacture or sale of high-grade multiblade fans, to form sales agency with advertiser. Product in use for years in highest grade buildings and plants. Financial connections and references must be of the best. Application by letter. Salary not stated. Location, New York City. R-1510.

DRAFTSMAN experienced on general power house work and familiar with high press piping. Application by letter. Salary not stated. Location, New York City. R-1520.

STEAM ENGINEER, technical graduate, about 30 years of age, with 5 years' experience in power plant design and layout of mechanical and electrical power equipment, some operating experience desirable to fill permanent position as assistant to steam engineer in large chemical company. Application by letter giving detailed list of positions held in last 10 years, references and salary desired. Location, Northern O. R-1534.

DRAFTSMAN over 21 years of age for electrical power switchboard-drafting work, who has had at least 4-5 years' experience and capable along that line in every detail. Application by letter. Salary not stated. Location, New Jersey. R-1536.

COMPETENT COMBUSTION ENGINEER with college education, shop and plenty of boiler combustion experience to supervise and make adjustments to combustion control systems. Application by letter giving full information in answer. Salary not stated. Location, Pa. R-1538.

POWER HOUSE DRAFTSMAN, capable draftsman wanted with considerable experience in power house design, including steam turbine installation, auxiliaries, piping, boilers and coal handling. Application by letter. Salary not stated. Location, Maryland. R-1539.

SALESMEN-ENGINEERS wanted to distribute the product of one of the oldest and best known precision instrument manufacturers on liberal commission basis. Territories open in all parts of the country. Add to your line or take on this line if you are in touch with architects, engineers, builders, etc. and want agreeable lucrative work. Application by letter. R-1540.

DRAFTSMAN for power plant layout. Experienced man only. Application by letter. Salary not stated. Location, New York City. R-1558.

DRAFTSMAN on general construction work, capable of designing industrial buildings, making machinery layouts, piping layouts, and ordinary machine design, checking drawings made by others. Application by letter. Salary not stated. Location, Va. R-1567.

ELECTRICAL DRAFTSMAN for design of electrical instruments. Application by letter. Salary not stated. Location, New Jersey. R-1598.

MAN with experience on design of finished product rather than production and methods. Application by letter. Salary not stated. Location, New York. R-1599.

ASSISTANT PROFESSOR in electricity, mathematics, and physics, in a State Technical Institution. Application by letter, stating age, training, experience, and inclosing photograph. Salary not stated. Location, Mass. R-1621.

YOUNG MAN having had an electrical training and some accounting experience to maintain plant and operating records. Application by letter. Salary not stated. Location, New York City. R-1634.

SALES ENGINEER who has acquaintances among dry docks, shipbuilders, naval architects. Application by letter. Salary not stated. Location, New Jersey. R-1635.

YOUNG ENGINEER thoroughly familiar with the latest theories and developments of radio and also having natural sales ability for the position of sales engineer or possibly sales manager in our corporation. Application by letter. Salary not stated. Location, New Jersey. R-1642.

MECHANICAL DRAFTSMAN to act as checker on small parts of oxweld acetylene equipment. Application by letter. Salary not stated. Location, New Jersey. R-1647.

ENGINEERS having had conveyor layout or structural steel design experience, to do designing work on industrial conveyor machinery, pneumatic and package handling conveyors. Application, by letter. Salary not stated. Location, New York State. R-1657.

SALES ENGINEERS, having had considerable experience on conveyor lines, pneumatic package handling conveyors. Application by letter. Salary not stated. Location, New York State. R-1658.

DRAFTSMAN having had conveyor layout or structural steel drafting experience, to do drafting work on industrial conveyor machinery, pneumatic and package handling conveyors. Application by letter. Salary not stated. Location, New York State. R-1659.

LIVE WIRE HIGH CLASS SALESMEN WANTED. Unusual opportunity for experienced salesmen (preferably with cars), to sell latest six tube radio frequency set. Perfect reproduction. Guaranteed, without any interference. Eastern states territory rights now available. High grade proposition. Cash profits. Only responsible parties need apply. Application by letter. Salary not stated. R-1666.

INSPECTOR for public utility company. Application by letter. Salary not stated. Location, N. Y. R-1671.

DESIGNING DRAFTSMAN experienced on industrial building work, steel mill building construction, power plants and conveyor and machinery equipment. Application by letter. Salary not stated. Location, New York City. R-1673.

ELECTRICAL ENGINEERING DRAFTSMAN for lighting and power work and conveying experience for railroads. Application in person. Salary not stated. Location, N. Y. C. R-1676.

DESIGN ENGINEER to specialize on winding, insulation and process engineering. Must be technical graduate. Experience in machine design, research or process work desirable but not essential. Application by letter stating training, qualifications and stating salary expected. Location, Pa. R-1681.

BUYER for light and heavy mill supplies who has had a technical education along mechanical and electrical engineering lines, preferably former, but one who is inclined to commercial side of business and has not been engaged in actual engineering so long that possibility of making satisfactory buyer and fitting in with large organization would be difficult. Age 26-32, preferably married. Application by letter. Salary not stated. Location, Ohio. R-1682.

ELECTRICAL DRAFTSMAN (3), with at least six years' experience on power house, outdoor substations, switchboard wiring diagrams and transmission line experience. Application by letter. Salary not stated. Location, New York City. R-1685.

CHIEF DRAFTSMAN who has had experience on either air compressors or pumps; preferably both. 12 in. compressors and shotter, and 12 in. on duplex steam and power pumps. To keep line modernized and not to make plant all over and bring out a lot of new designs. Application by letter. Salary not stated. Location, Mid-West. R-1686.

DRAFTSMEN familiar with modern foundry equipment or cast iron boiler experience preferred or experienced in machine design to do drafting work in connection with the changing of an old foundry in existance for more than fifty years from a hand ramming foundry to machine ramming with the necessary changes in the patterns and equipment, also changes in the foundry to increase production. This will necessitate building some machines. Application by letter. Salary not stated. Location, Conn. R-1687.

COMBUSTION ENGINEER, technical graduate with 4-5 years' experience along combustion and steam engineering lines. Application by letter. Salary not stated. Location, O. R-1694.

RECENT TECHNICAL GRADUATES OR MEN with one or two years' experience for experimental work along combustion and steam engineering lines. Application by letter. Salary not stated. Location, Ohio. R-1695.

FOREMAN for company manufacturing electrolytic iron. Man between 40-50 years old with technical education preferred. Must also have executive experience. Application by letter stating age, education and experience. Salary not stated. Location, Conn. R-1703.

ELECTRICAL ENGINEER with several years' experience on layout of power and light and telephone circuits and able to supervise

nstallations. Application by letter. Salary not stated. Location, New York City. R-1708.

ENGINEER with experience in metallography, ferrous-metallurgy and electro-metallurgy: for research and teaching with advanced and graduate students: in cooperation with allied lines in economic geology given by representative of the Geological Survey. Application by letter. Salary depends, but commensurate with experience and qualification fitting candidate to work. Location not stated. R-1710.

DRAFTSMEN, preferably men with some practical experience in mill construction designing. Application by letter. Salary not stated. Location not stated. R-1712.

ELECTRICAL FORMAN. Large rubber corporation desires services of an EXPERIENCED ELECTRICAL FORMAN, preferably with technical training to take charge of construction, maintenance, winding and rebuilding of all types of motors and generating equipment. Prefer man 30-40 years old who has had industrial training and capable of handling men. Permanent position and good salary. Application by letter. Location, Mid-West. R-1718.

PRODUCTION EXECUTIVE for plant manufacturing electric motors and generators. Must possess judgment, common sense, and have had past experience in electrical motor and generator field. Man capable of directing orders through plant to meet shipment dates, also be able to supervise small force of men, production chasers. Application by letter stating age, education and experience. Salary not stated. Location, Northern New Jersey. R-1719.

ELECTRICAL RATE SETTER for concern manufacturing electric motors and generators. Application by letter stating age, education and experience. Salary not stated. Location, Northern New Jersey. R-1720.

MASTER MECHANIC with experience in cotton piece goods finishing plant for a small plant near Atlanta. Application by letter giving full details of experience and salary expected in letter of application. R-1723.

CONSULTING ENGINEER located in Chicago engaged in power plant and industrial plant construction desires a partner to act in the capacity primarily of business manager and business getter. Should be acquainted throughout Middle West, should have general knowledge of power plant work and be a No. 1 salesman. Moderate investment required. Application by letter. R-1727.

SALES ENGINEER to take charge of Atlanta office and travel in states of North and South Carolina, Virginia, Tennessee, Georgia. Alabama and Florida. Must have good general education, some engineering training, either practical or theoretical and at least two years' sales experience in power plant specialties or allied lines. Application by letter. Salary, expenses and bonus. Headquarters, New York. R-1728.

SALES ENGINEER to operate out of Boston office and cover New England territory. Must have good general edueation, some engineering training, either practical or theoretical and at least two years sales experience in power plant specialities or allied lines. Application by letter. Salary, expenses and bonus. Headquarters, N. Y. R-1729.

MASTER MECHANIC to take charge of manufacturing and production of sheet metal and screw machine shop. Application by letter. Salary not stated. Location, N. J. R-1736.

SUPERINTENDENT for operation of hydroelectric station situation on Pacific Coast. Must be good mechanic and experienced operator, married man preferred. Application by letter stating age, education, experience, references, present salary and salary expected. Location, Washington. R-1738.

ENGINEER with practical experience to take charge of 2300 and 4000-volt overhead distribution and 6600-13200-volt transmission calculations, records, and etc. Application by letter. Salary not stated. Location, La. R-1748.

ASSISTANT ENGINEER who would make power and secondary calculations, and estimates for 2300 and 4000-volt overhead distribution and 6600-13200-volt transmission calculations, records, etc. Application by letter. Salary not stated. Location, La. R-1749.

SUPERINTENDENT of malleable iron-foundry. Must have a complete knowledge of all departments of foundry work, and ability to handle 300 men, mostly Americans. Must have had several years' practical experience in executive management of malleable iron foundry. Application by letter. Salary not stated. Location, New England. R-1490.

SET UP MAN for O. O. or No. 19 Brown and Sharpe automatic screw machine. Must have this experience. Application by letter. Salary not stated. Location, New Jersey. R-1500.

ENGINEERS to sell Industrial Service to manufacturers. Application by letter. Commission basis. Location not stated. R-1509.

SALES ENGINEER for foreign sales work with experience in pumps and condensers. Application by letter. Salary not stated. Location, Cuba. R-1615.

SUPERINTENDENT for operation of hydroelectric station situation on Pacific Coast. Must be good mechanic and experienced operator, married man preferred. Application by letter stating age, education, experience, references, present salary and salary expected. Location, Washington. R-1738.

SALESMAN to sell our products. Must have knowledge of packing jobbers trade, and have sold this product before, or mechanical rubber goods to this class of merchant. Application by letter. Commission basis. Location not stated. R-1739.

TESTING, and investigation for electric steam power plants. Experience in small plant study desirable. Application by letter. Salary not stated. Some traveling. R-1750.

PRODUCTION ENGINEER for company manufacturing radio equipment. Application by letter. Location, not stated. R-1771.

ASSISTANT ENGINEERS power plant building work. Must be able to correlate work from inception in drawing room to requisitioning of materials. Applicants to be capable to direct steel and building design, specifications, analyses of bids, and negotiate engineering details with purchasing agent and contractors. R-1773.

TECHNICAL GRADUATES (3) in large electrical laboratory. Work is closely connected with electric, and physical measurements and offers an unusually good opportunity for extensive experience and advancements. Men who apply should be adapted by inclination and training to development and research work. Location, West Lynn, Mass. R-1789.

SEVERAL MEN (2) for an electrical laboratory connected with large manufacturing plant want men who have experience on meters or instruments. Must be at least high school graduates and ambitious to develop along engineering lines. Opportunities for good men unusual. In replying give complete details of experience and training. Location, West Lynn, Mass. R-1790.

RECENT GRADUATE for power sales work in growing utility. Location New York State. R-1791.

ELECTRICAL ENGINEERING GRADUATE to enter service sales department of X-ray manufacturing concern in Middle West. Some sales experience preferred but not essential. Character, address and intelligence must rank high. Exceptional opportunity to enter high class service and sales organization selling best products. Location, Middle West. R-1796.

STEAM ENGINEER. Technical graduate between 30-35 who has spent most of work on steam and power problems in industrial organization. Must be thoroughly qualified to supervise steam and power of company whose plants aggregate 50,000 h. p. Send detailed information, photograph and indicate compensation desired. Must be willing to travel extensively. Location, not stated. R-1779.

GENERAL ENGINEER, mechanical graduate of executive ability, with wide experience in steam and power work for one of the largest industrial companies in the country. Construction experience not necessary. Proof of ability to handle engineering department required. Give full experience approximate salary requirements, small untouched snap shot. Location, Ivorydale, Ohio. R-1778.

DESIGN ENGINEER to specialize on winding, insulation and process engineering. Must be technical graduate. Experience in machine design, research or process work desirable but not essential. Application by letter stating training, qualifications and starting salary expected. Location, Pa. R-1681.

ELECTRICAL FOREMAN. Large rubber corporation desires services of an experienced electrical foreman, preferably with technical training to take charge of construction, maintenance, winding and rebuilding of all types of motors and generating equipment. Prefer man between 30-40 years old who has had industrial training and capable of handling men. Permanent position and good salary. Application by letter. Location, Mid-West. R-1718.

ENGINEER, in charge of power, repair and construction work. College graduate in mechanical or electrical engineering. Age 30-35 years. Experienced in modern boiler and engine practise, and in generation, distribution and utilization of electrical energy. Must be capable of handling mechanics, etc. Application by letter. Salary not stated. Location, Middle West. R-1781.

SUPERINTENDENT of steam plant substations. Technical and practical experience in both mechanical and electrical engineering and it is essential that he should have had actual operating experience in steam generating plants. Must be capable of operating and maintaining steam plant, substations and meter department, which come under his supervision in an efficient manner. Also able to make up plans and estimate for any improvements or additions. Application by letter. Salary not stated. Location, West Indies. R-1763.

JUNIOR ELECTRICAL ENGINEER, 1923 graduate for work in public utility in greater New York. Application by letter. Salary not stated. R-1764.

ASSISTANT TO PLANT ENGINEER for company manufacturing electrical supplies. Application by letter. Salary not stated. Location, New Jersey. R-1769.

INSTRUCTORS

INSTRUCTOR IN ELECTRICAL ENGINEERING. Work consists of Electrical Engineering Laboratory and a class in either Radio or Telephony. Prefer a man with from 1 to 3 years' experience. Salary depends on qualifications. Application by letter. Location, South. R-879.

INSTRUCTOR to teach Machine Design, Internal Combustion Engines and M. E. Laboratory in southern university. Prefer man with practical or teaching experience in these subjects. Must be technical graduate. Work lasts nine (9) months, starting September. Small classes. Application by letter. Salary not stated. Location, South. R-1017.

GRADUATE ENGINEER to teach mechanics and assist in testing laboratory. Teaching experience preferred, but not essential. Application by letter. Salary not stated. Location, Pa. R-1220.

INSTRUCTOR for employes' classes in organized educational department of a large electric utility corporation. Must be Electrical Engineering graduate with experience in teaching and in an operating company desirable. Write full particulars and state salary acceptable for first year, beginning not later than August 1st.

Also enclose kodak photograph. Application by letter. Location, Ill. R-1264.

INSTRUCTOR for employes' classes in organized educational department of a large electric utility corporation, also having gas properties. Must be a technical graduate with experience in teaching and in operating company. Principal classes, Manufacture and Distribution of Gas and Steam Engineering. Write full particulars and state salary acceptable for first year, beginning not later than August 1st. Also enclose kodak photograph. Application by letter. Location, Ill. R-1265.

ELECTRICAL ENGINEER having had 1-2 years' post graduate study and at least 10 years' experience of which at least 3 years must have been in teaching, to fill position of Associate Professor of E. E. Application by letter. Salary not stated. Location, Iowa. R-1298.

INSTRUCTOR to teach mechanical laboratory, elementary engines and boilers, and gas engines. Must be technical graduate. Some experience desirable. Term beginning in September. Application by letter. Salary not stated. Location, South. R-1323.

RECENT GRADUATE ELECTRICAL ENGINEER to teach radio engineering. Application by letter. Salary not stated. Location, Ga. R-1329.

RECENT GRADUATE to teach mathematics. Application by letter. Salary not stated. Location, Ga. R-1330.

INSTRUCTORS (4) in machine design and descriptive geometry. 2 years' drafting experience on machine design with reputable company. Application by letter. Salary not stated. Location, South. R-1331.

MECHANICAL ENGINEER, as teacher in mechanical drawing, thermo-dynamics and hydraulics, etc. Must be graduate of a technical school. Application by letter, stating degrees, experience, salary desired, etc. Location, Southwest. R-1344.

INSTRUCTORSHIP in Mechanical Engineering in southern university. Courses vacant are: internal combustion engines for fourth year students, and lectures and laboratory covering all phases of engineering shopwork. Application by letter giving full details of education, experience and also references. Location, Texas. R-1347.

RECENT GRADUATES to go through training course in factory, manufacturing electric fixtures, preparatory to more responsible position. Application by letter. Salary not stated Location, Conn. R-1350.

INSTRUCTOR with one year's teaching experience, for Department of Electrical Engineering. Application by letter. Salary not stated. Location. Middle West. R-1400.

INSTRUCTOR for Department of Electrical Engineering. Application by letter. Salary not stated. Location, Middle West. R-1401.

INSTRUCTOR, School of Mechanical Engineering. Must be a Mechanical Engineering Graduate, and should have had one or two years' practical experience. Application by letter. Salary not stated. Location, Pa. R-1415.

ELECTRIC DISTRIBUTION ENGINEER with experience in over head lines. Application by letter. Salary not stated. Location, Central America. R-1421.

CHIEF DRAFTSMAN in our Engineering Department, familiar with the design and construction of special apparatus and machinery, also with machine shop practise, and capable of putting out drawings in our shop with the necessary information on them, so that the shop is fully informed as to just what is wanted. Application by letter. Salary not stated. Location, New York State. R-1471.

ASSISTANT PROFESSOR IN GENERAL ENGINEERING DRAWING. Must be a graduate of a recognized technical school, with engineering experience. Application by letter. Salary not stated. Location, Illinois. R-1472.

INSTRUCTOR in Mechanical Engineering to teach elementary theory of steam and gas engineering and to assist in teaching of classes in mechanical engineering laboratory practise. Duties begin first of September and continue for nine months. Must be mechanical engineering graduate. Teaching experience not essential but desirable. Application by letter. Salary not stated. Location, West. R-1524.

INSTRUCTOR to teach General Engineering at college in Department of Civil Engineering. Desire young energetic man with preferably some practical and teaching experience. Must be able to teach Engineering Drawing, Descriptive, Geometry, Graphic Statics, Elementary Engineering, including Civil, Electrical and Mechanical and Preparatory Physics. Application by letter. Salary not stated. Location, South. R-1526.

STEAM ENGINEER, technical graduate, about 30 years of age, with 5 years' experience in power plant design and layout of mechanical and electrical power equipment, some operating experience desirable, to fill permanent position as assistant to steam engineer in large chemical company. Application by letter giving detailed list of positions held in last 10 years, references and salary desired. Location, Northern, Ohio. R-1534.

INSTRUCTOR in descriptive geometry for college in Middle West. Mechanical Engineer preferred. Application by letter. Salary not stated. Location, Middle West. R-1601.

INSTRUCTOR in mechanical and machine drawings, in a State Technical Institution. Application by letter stating age, training, experience, and photograph. Salary not stated. Location, Mass. R-1620.

ASSISTANT PROFESSOR in electricity, mathematics, and physics, in a State technical institution. Application by letter, stating age, training, experience, and enclosing photograph. Salary not stated. Location, Mass. R-1621.

INSTRUCTOR in machine drawing in a large mid-western State College; a recent graduate mechanical or electrical engineer. Application by letter. Salary not stated. Location, Kansas. R-1631.

ASSISTANT SUPERINTENDENT of foundry laboratory in large University in Middle West. College graduate about 26 years old with practical foundry experience who desires to enter the teaching profession and to engage in research of foundry problems. Application by letter. Salary not stated. R-1499.

INSTRUCTOR, Mechanical Graduate. Would devote time to teaching drafting to boys, and should have had some trade contract, since boys are usually learning some trade other than drafting. Teaching experience desirable though not necessary. Opportunity for developing into an administrative position very good. Application by letter. Salary not stated. Location, Pa. R-1690.

INSTRUCTOR, Technical Graduate with some shop experience if possible to teach science, mathematics and perhaps some general subjects. Application by letter. Salary not stated. Location, Pa. R-1691.

RECENT GRADUATES

RECENT GRADUATE ELECTRICAL ENGINEER, must have good personality. Application by letter. Salary not stated. Location, New York City. R-1417.

RECENT GRADUATE to do research work in connection with heating problems. Application by letter. Salary not stated. Location, New York City. R-1418.

RECENT ELECTRICAL ENGINEER to do engineering and sales work, in connection with small motors. Application in person. Salary not stated. Location, New York City. R-1434.

RECENT GRADUATES (2) 1923, to do inspection work on underground conduits and cables. Application by letter. Salary not stated. Location, Pa. R-1454.

1923 GRADUATE MECHANICAL ENGINEER for apprentice course leading to sales. Salary $100 for the first 6 months, $110 per month the 2nd 6 months and $130 at the beginning of the 2nd year. Application by letter. Location, not stated. R-1465.

ENGINEER to take charge of our engineering department of a chemical plant. Problems encountered are similar to those encountered in most chemical plants such as black ash buring, lixiavation, calcining, washing, filtering and drying. Application by letter. Salary not stated. Location, Delaware. R-1473.

RECENT GRADUATE to start with an engineering firm doing sanitation work. Application by letter. Salary not stated. Location, New York City. R-1481.

RECENT GRADUATE to do promotional work for a New England manufacturer of steam power plant machinery. Application by letter. Salary not stated. Location, New England. R-1483.

RECENT GRADUATE ELECTRICAL ENGINEER, Cornell, M. I. T. or Columbia Graduate preferred, for general engineering work along transmission and distribution lines. Application by letter. Salary not stated. Location, New York City. R-1575.

RECENT ELECTRICAL ENGINEER for general engineering work for company manufacturing storage batteries. Must have good personality and be able to meet executives. Application by letter. Salary not stated. Location, New York City. R-1588.

DESIGNERS. Reinforced and structural steel on industrial buildings. Application by letter. Salary not stated. Location, Cal. R-1607.

RECENT GRADUATE to make dynamometer tests on gas engines. Must have some knowledge of motor fuels. Application by letter. Salary not stated. Location, New York City or New Jersey. R-1609.

RECENT GRADUATE ELECTRICAL ENGINEER, to assist manager in show room, work into sales for X-ray supply company. Application by letter. Salary not stated. Location, New York City. R-1617.

DRAFTSMAN experienced in laying out floor plans for equipping factories with machinery, etc., for economic production. Rubber factory experience preferred. Application by letter, stating age, experience past positions and salary expected. Location, New Jersey. R-1624.

YOUNG MAN preferably just out of college and with the usual technical training that goes with a course in mechanical engineering. Should, however, have a particular leaning toward the commercial or selling side of the machinery business, as this is a sales office, first, last and all the time. Work will be varied. It will cover the laying out of mechanical power transmission and conveyor equipments; with particular care to use material carried in stock as far as possible and therefore with as little special material or material that must be made to order, as circumstances will permit. He will also have to sketch out, when necessary, timber, and steel supports for carrying the machinery that will be safe and economical. Figuring up estimates of selling price and the ability to dictate a clear cut sales letter. It will be necessary for him to go outside in sales work more and more as his experience with the business increases and with the idea that eventually all his time will be devoted to outside sales work. Application by letter. Salary not stated. Location, New York City. R-1625.

GRADUATE MECHANICAL ENGINEER with a few years' experience preferably around copper mines and smelter, work will be mainly repair and maintenance of smelting work mines and small transportation system. Excellent opportunity for young man to get good experience. Fine climate and working conditions. Application by letter, stating fully education, training, experience and references. Salary not stated. Location, Cal. R-1626.

INSTRUCTOR in machine drawing in a large mid-western State College; a recent graduate mechanical or electrical engineer. Application by letter. Salary not stated. Location, Kansas. R-1631.

RECENT GRADUATES to be trained partly in the office in N. Y. and partly in our factory at Buffalo, to prepare them for service abroad. Unless a man feels that he is prepared to go abroad and make his career there for a period of years, he is out of place in the organization of a Dye and Chemical Co. Men of character and ability with high ideals, ambitious to get on, and who appreciate that such progress depends on hard work, close application and the exercise of common sense and sound judgment. A knowledge of some foreign language is necessary for certain markets, but in all cases the candidate must by his mental make-up and disposition be above provincial restrictions, and have a real sympathy with the ideals and psychology of the foreign people among whom he may be expected to live. Application by letter. Salary not stated. R-1639.

RECENT GRADUATES who are willing to start at the bottom in mechanical department of a sheet and tin plate company as machinists, electricians, millwrights, etc. Application by letter. Salary not stated. Location, not stated. R-1713.

RECENT GRADUATE ENGINEER. Application by letter stating age, education and experience. Salary not stated. Location, Conn. R-1722.

YOUNG ENGINEERING GRADUATE to go through course of training in shop and office to qualify for position of Sales Engineer. Training comprises at least 3 months' shop experience and at least 1 year at head office as sales correspondent with occasional selling and service trips. Application by letter. Nominal salary paid while training. Location, not stated. R-1730.

RECENT MECHANICAL ENGINEER to do investigation work in connection with marketing condition of petroleum position. Will develop into sales work. Application by letter. Salary not stated. Location, New York City. R-1733.

RECENT MECHANICAL ENGINEER 1922-1923 to go through training course for firm manufacturing industrial heating appliances and coal gas making machinery leading to plant, operating, and construction positions. Application in person Salary not stated. Location, New York City. R-1735.

RECENT GRADUATE to do general office work in sales office of company handling power specialities and refrigeration equipment. Application by letter. Salary not stated. Location, New York City. R-1737.

RECENT GRADUATES, Mechanical Engineering for company manufacturing fluid meters. Application by letter. Salary not stated. Location, Mid-West. R-1641.

RECENT 1923 GRADUATES, Mechanical Electrical, or Chemical Engineers for training course in gas company for industrial sales work. Application by letter. Salary not stated. Location, New Jersey. R-1651.

RECENT GRADUATE for mills, forges and open hearth departments of a steel company in Pennsylvania who are willing to commence at bottom and spend the years necessary to learn these branches of the business from ground up. Application by letter. Salary not stated. R-1683.

MEN AVAILABLE

MECHANICAL AND POWER ENGINEER. Eight years' broad experience, machine shop, sugar refinery, industrial and power plant design, layout, construction, heat-balance, steam, water power requirements, investigation and reports. E-4384.

YOUNG MAN 23, S. B. in electrical engineering from M. I. T. One year W. E. & M. Co. small motor engineering and test. Seven months power plant design. Desires position in power plant design or operation; preferably with a public utility company. At present employed. E-4385.

ELECTRICAL ENGINEER. Age 30, technical graduate desires position along qualified lines. Experience includes Westinghouse test, testing and research at Bureau of Standards, three years responsible charge of experimental and testing laboratory in motor manufacturing concern and past two years engaged in teaching electrical engineering and physics. Has studied accountancy and cost accounting. Available within reasonable time. E-4386.

SEMI-TECHNICAL MAN with several years practical experience seeks position with electrical power company, in engineering department. Experience rather than big pay desired. Will go anywhere. E-4387.

PUBLIC UTILITY ENGINEER or EXECUTIVE. Specialist in management problems: Valuation; financial studies; engineering reports; statistical analyses; budget planning and direction; construction, maintenance and operating estimates; rates; taxes; insurance; coordination of engineering; construction and operation with accounting practise, etc. Can qualify for responsible position with electric railway utility management corporation, consulting engineer or public commission. Associate of A. I. E. E. Technical course preceded by 1½ year college preparatory and 4 years commercial course. Age 34, married. Tolerant, Protestant. Available 30 days. E-4388.

YOUNG MAN age 25, has E. E. degree 1921 and post graduate work in Columbia University, is looking for an opening with some organization. Has two years' experience in teaching physics, but is now interested in manufacturing, testing or public utility. A career is sought in this or allied fields. Associate A. I. E. E. Will go anywhere. Available at once. E-4389.

ELECTRICAL ENGINEER. University graduate, 20 years' experience in the electrical and mechanical manufacturing business, 7 years in designing, 4 years in production and assisting in the management of a small plant. Capable of taking charge and directing men. Desires position in a small or medium size plant in assisting the management. Location Newark or New York, Newark preferred. Can start on reasonable notice. E-4390.

GRADUATE ELECTRICAL ENGINEER. Married, age 27, desires position in power plant, paper mill or manufacturing plant in a small city where there is an opportunity to advance and assume responsible position. Location desired middle west. Salary expected $200. per month. E-4391.

GRADUATE ELECTRICAL ENGINEER. Age 28, unmarried. Has had experience on G. E. Test, design and construction of power stations and high-tension transmission systems, valuation of public utilities and in the manufacture of radio apparatus. Desires position of responsibility with opportunity for advancement. E-4392.

YOUNG MAN, age 24, single. University graduate in E. E., one year experience in sales office, drafting, sugar mill electrification, and with public utility on reconstruction and plant betterment work, desires position with public utility or an instructor in technical institution where graduate work can be carried. E-4393.

ENGINEER, M. E. and Ph. B. degrees, specialized in electrical engineering; several years' practical experience desires assistant professorship of electrical engineering in North America or where the English language is usually spoken. Age 38. E-4394.

ELECTRICAL ENGINEER B. S. degree, age 32, single. Four years' practical experience along lines of light and power distribution and industrial installations and maintenance. For past three years has been assistant professor of mathematics and electrical engineering in New England. Now desires to make a change and to locate in the southern states or in California. Would consider either teaching or industrial offer. Salary $3000. E-4395.

ENGINEERING EXECUTIVE. Technical Graduate, 10 years' experience, valuation, production cost and job analysis, time study and control, construction engineering and design, wishes to affiliate with growing manufacturing organization or industrial engineering company, age 30, American citizen. Married. E-4396.

ELECTRICAL ENGINEER age 30, single, college graduate, Westinghouse students' training course, power plant experience, desires opportunity for permanent position with consulting engineer, public utility or electric railway company. Eastern state preferred. E-4397.

1919 GRADUATE of the E. E. course at Cooper Union Institute, degree of B. S., age 26. Has had 2 years of d-c. machinery testing, and five years' experience as electrician on electric light and power installation. Would like a position with electric light and power or mining concern. Main consideration chance for experience. Location immaterial. E-4398.

MATERIALS AND PROCESSES ENGINEER. Electrical and mechanical engineer with good metallurgical training and experience, who held responsible positions in designing and engineering departments and for the last six years has specialized exclusively in investigating, developing and introducing new material and processes for one of the largest American manufacturing concerns, would be willing to change present position for another in charge of similar work if sufficiently attractive inducements are offered. Is running his own laboratory and also general commercial application department. Can prove excellent record in savings and improvements. E-4399.

RESEARCH PHYSICIST. Ph. D., age 40; employed during last six years with large manufacturing concern where fair opportunity has been given for directing research work and doing executive work. Desires position where greater opportunity is to be found for organizing and directing research. Has a very wide acquaintance both among university and industrial research men; is thoroughly familiar with modern physics. Salary open. E-4400.

ELECTRICAL ENGINEER. Technical graduate, age 28, single. 10 years' practical electrical construction and maintenance experience. Desires position either in sales operation or construction work. Willing to travel if necessary. Available immediately. E-4401.

POWER PLANT DESIGNER. University gratuate, seven years' designing and construction experience on large and small power plants, substations and transmission lines. At present employed on responsible work by large engineering concern outside of New York City, desires responsible position on power plant work in New York City. E-4402.

ELECTRICIAN with thorough practical and technical training, 20 years' experience construction and maintenance. Age 38, open for position. Good worker, personality, physique and health good. E-4403.

ELECTRICAL ENGINEER. Technical from I. C. S. Age 25 years. Experience along the lines of industrial plant maintenance and power and lighting installation. E-4404.

TECHNICAL GRADUATE. Age 31, with nine years' practical experience, installing, maintaining and supervising work on industrial electrical wiring and equipment, desires position with an electrical construction firm or large manufacturing plant. E-4405.

ELECTRICAL ENGINEER. University graduate, 28 years of age, at present employed, desires change. Formerly in charge of power plant department of European manufacturing company. Has successfully carried out investigation on theoretical and practical subjects of electrical engineering. Throughout theoretically trained in problems of current and voltage protection of power systems. Right kind of work and chance for advancement and higher

responsibility more desirable than salary to start with. Location immaterial. Available on notice. E-4406.

YOUNG MAN, 1920 graduate electrical engineer with engineering and business experience, knowledge of theoretical and practical accounting wishes position in engineering or allied work where there are opportunities for advancement. E-4407.

SALES ENGINEER Graduate in both mechanical and electrical engineering. 15 years experience in office, executive and field sales work. 37 years old. Married. Available for whole or part time or to act as Eastern representative with headquarters in New York. Has own office. Can take up new work on short notice. E-4408.

ELECTRICAL ENGINEER. Age 37, with 17 years' experience on design, construction, and operation of power and substations, transmission systems, electrification problems, light, layouts, specifications, reports, handling economical problems in connection with industrial plants and buildings, fuel analysis, operating characteristics of electrical and mechanical apparatus and advanced research work, desires position where executive ability is required. Fellow and member of many engineering and scientific societies. E-4409.

SALES ENGINEER. Graduate electrical engineer, age 29, single, has had seven years' experience in the development of telephone and telegraph apparatus, refrigerations and ventilation. Recently engaged in a field survey relating to sales. Has had a thorough training in business correspondence and traveled extensively. Desires position as sales engineer. E-4410

ELECTRICAL ENGINEER. Age 26, Graduate. Four years varied experience design and construction, mechanical and electrical. Wants opportunity to develop into sales engineer; prefers New York City and vicinity. E-4411.

ELECTRICAL ENGINEER. Technical, graduate, age 33 years, married, 12 years' experience in testing, appraisal, inspection, design, desires responsible position in connection with design and layout of power houses, substations, feeders etc., for railroad, utility or industrial plant. Can take charge of drafting room. Present position, designing electrical engineer in rubber manufacturing plant, present salary $3000. Interview in New York or vicinity in September. E-4412.

TECHNICAL GRADUATE in electrical engineering courses and one year training in mechanical course. Age 24, desires position with electric and manufacturing or engineering concern where a good future is assured. Now employed as electrical sales correspondent, formerly in testing department of large public utility. Trained to think, ambitious, capable, hard worker. E-4414.

ELECTRICAL ENGINEER. Technical graduate, Associate A. I. E. E., age 25, single, 5 years, experience as assistant to meter superindent, can test, repair and install all commercial types of watt-hour meters. Now employed with large utility company, having in service 20,000 meters. Desires position as meter superintendent with utility company. Available on reasonable notice. E-4413.

ELECTRICAL DESIGNING ENGINEER. Technical graduate of university, associate A. I. E. E., age 25, single. Three years' experience on design of hydroelectric generating and transformer stations, one year in construction work. Now with firm of consulting engineers, but desires connection with company offering opportunity for advancement. E-4415.

WANTED. Position in manufacturing company or public utility, graduate in E. E., experience at Westinghouse test, several small shops, radio work, can carry out investigations and turn in good reports, two years, teaching experience, age 28, single, good health. E-4416.

DESIGNING AND ESTIMATING ENGINEER. Ten years' experience with heavy electric overhead traveling cranes, large sluice gates, head gates and miscellaneous hoisting and conveying machinery. Electrical training and some executive experience. Age 30. E-4417.

ELECTRICAL ENGINEER with three years' plant construction experience, G. E. Test, one and one half years general engineering on generating stations, substations, transmission lines, and distribution systems, desires position in the engineering department of public utility. E-4418.

ENGINEER desires position as assistant to executive. Four years in G. E. test and shops, six years layout, sale and installation of equipment in industrial plants, power contracts negotiations and rates. Five years assistant engineer of the Quaker Oats Company. Two years research engineer of public utility. Technical graduate, associate A. I. E. E., age 35, married. Will locate anywhere. E-4419.

PARTNER ELECTRICAL ENGINEER with eight years' experience in construction and operation with public utilities companies in the United States and abroad, with a small amount of capital to invest, would like an active interest in a growing contracting firm. Preferably in the middle west. E-4420.

ELECTRICAL ENGINEER. Graduate of well known middle western school, with fifteen months practical electric railway experience and six months sales experience desires position as sales engineer, preferably of electric railways supplies, though others will be considered. E-4421.

ELECTRICAL ENGINEER 30 years old, Associate A. I. E. E., desires position with power plant or large public utility as assistant to chief engineer or superintendent, offering opportunity of advancement. Eight years' experience along lines of light and power distribution, industrial installation and maintenance, Westinghouse Electric & Mfg. Co. experience in switchboard and power plant construction and wiring diagrams. Has had foreign experience, speaking Spanish perfectly. Now employed, but available at short notice. E-4422.

EXPORT SALESMAN ENGINEER, acquainted with Latin America, Italy and Philippines, capable of designing and installing power, refrigerating, pumping and wood-working plants, extensive traveling experience, selling for leading machinery concerns, knowledge of Spanish and Italian. Now employed, but will consider connection with progressive concern desiring an energetic, high grade foreign representative. E-4423.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before August 31, 1923.

Albertson, D. E., East Penn Electric Co., Pottsville, Pa.
Arias, B. E., Telegraph Line Construction, Mexico, D. F., Mex.
Bain, J. W., Canadian Westinghouse Co., Hamilton, Ont.
Basford, C. R., Underwriters Association, Philadelphia, Pa.
Bourke, L. J., Washington Coast Utilities, Seattle, Wash.
Burnett, W., Jr., Peabody Coal Co., Marian, Ill.
Carpenter, E. E., (Member) British Columbia Railway Co., Ltd., Vancouver, B. C.
Collier, C. A., (Member), Georgia Railway & Power Co., Atlanta, Ga.
Conley, D. L., Alabama Power Co., Muscle Shoals, Ala.
Crane, E. B., Erie Lighting Co., Erie, Pa.
Grandall, E. D., Public Service Production Co., Newark, N. J.
Cressman, C. S., Philadelphia & Reading Coal & Iron Co., Pottsville, Pa.
Cushing, R. G., (Member), Stone & Webster, Inc., Boston, Mass.
Daley, J. J., Electric Bond & Share Co., New York, N. Y.
Davis, G., Kentucky Light & Power Co., Fulton, Ky.
Dreyer, H. W., res., 2021 Dorchester Road, Brooklyn, N. Y.
Duvoisin, E. M., General Electric Co., Schenectady, N. Y.
Eberly, J. C., Firestone Tire & Rubber Co., Akron, Ohio
Eitel, H. C., Public Service Co. of Northern Illinois, Evanston, Ill.
English, W. C., Erie Lighting Co., Erie, Pa.
Foster, R. W., Western Union Tel. Co., Portland, Ore.
Fowler, W. H., Rochester Telephone Corp., Rochester, N. Y.
Greve, L. F., Commonwealth Edison Co., Chicago, Ill.
Griffith, G. M., Dallas Power & Light Co., Dallas, Texas
Haigis, C. D., Victor Talking Machine Co., Camden, N. J.
Hall, F. L., Beech Bottom Power Co., Power, W. Va.
Hansen, A. F., Southern Pacific R. R. Co., Dunsmuir, Calif.
Hayes, Winston, Camp Alfred Vail, N. J.
Heisley, N. C., Prior & Sallada Co., Williamsport, Pa.
Held, C. A., Porcupine Davidson Gold Mines, Porcupine, Ont.
Hogan, A. A., Pacific Gas & Electric Co., Oakland, Calif.
Hurtado, L., Compania Independiente de Luz y Fuerza, Mexico, D. F., Mex.
Illing, I. L., The Milwaukee Electric Ry. & Lt. Co., Milwaukee, Wis.
Kasnick, C. F., Public Service Co., Evanston, Ill.
Kenworthy, J. W., Wagner Electric Corp., W. Philadelphia, Pa.
Kirby, F. M., Edwards Electric Construction Co., New York, N. Y.
Kirkwood, A. C., res., 1531 Wood Ave., Colorado Springs, Colo.
Larralde, H., National Power Commission, Mexico City, Mex.
Little, E. G., Industrial Controller Co., Milwaukee, Wis.
Menke, C. H., Mississippi River Power Co., Keokuk, Iowa

Nordling, W. G., J. Livingston & Co., Inc., New York N. Y.
Nyerges, W. S., National Lamp Works, Nela Park, Cleveland, Ohio
Page, K. L., New York & Queens Elec. Lt. & Pr. Co., Bridge Plaza, Long Island City, N. Y.
Pamplona, R. L., General Electric Co., Schenectady, N. Y.
Ray C. H., American Tel. & Tel. Co., New York, N. Y.
Raymond, C. B., Portland Railway & Light Co., Portland, Ore.
Rerucha, E. A., res., Brainard, Nebraska
Riley, C. C., Submarine Signal Co., New York, N. Y.
Shea, T. E., Western Electric Co., New York, N. Y.
Shute, J. M., Central Illuminating Light Co., Peoria, Ill.
Sirotkin, G., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Smith, W. M., South-Eastern Underwriters Association, Atlanta, Ga.
Stockland, R. I., Western Electric Co., Inc., Chicago, Ill.
Stillman, C. B., Crocker-Wheeler Co., Ampere, N. J.
Tennant, F. A., (Member), Erie Lighting Co., Erie, Pa.
Topalian, Asadour; res., 36 Brackett St., Brighton, Mass.
Uphouse, W. F., Southwestern Bell Telephone Co., St. Louis, Mo.
Webster, G. A., National Carbon Co., Cleveland, Ohio
Werner, F., General Electric Co., New York, N. Y.
Whitney, L. H., General Electric Co., Pittsfield, Mass.
Wollaber, A. B., So. California Edison Co., Pasadena, Calif.
Wordal, O. J., 581 Van Buren St., Milwaukee, Wis.
Wylie, L., Chicago, Milwaukee & St. Paul Railway, Seattle, Wash.
Yonekura, J., Takata & Co., New York, N. Y.
Total 64.

Foreign

Cheshire, A. A., Sumner Borough Council, Christchurch, N. Z.
Judd, M. F., Public Works Dept., Wellington, N. Z.
Kuka, J. M., (Member), The Tata Mills, Ltd., Bombay, India
Lee, J. H., Public Works Dept., Wellington, N. Z.
Matsuo, H., Taiwan Electric Power Co., Taiwan Denryoku K. K., Formosa, Japan
McLennan, H. T. W., Dunedin Corp. Tramways, Dunedin, N. Z.
Ottonello, R. J., Ottonello, Tibaldi & Co., Buenos Aires, Argentine Republic, S. A.
Sarjeant, R., Riccarton Borough Council, Riccarton, N. Z.
Taranger, A., Western Electric Norsk A/S, Kristiania, Norway
Total 9.

OFFICERS OF A. I. E. E. 1923-1924

President

Harris J. Ryan

Junior Past-Presidents

Frank B. Jewett
William McClellan

Vice-Presidents

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W. I. Slichter
R. F. Schuchardt
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William F. James
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H. M. Hobart
Ernest Lunn
G. L. Knight
William McConahey
W. K. Vanderpoel
H. P. Charlesworth

Treasurer

George A. Hamilton

Secretary

F. L. Hutchinson

Honorary Secretary

Ralph W. Pope

LOCAL HONORARY SECRETARIES

Carroll M. Mauseau, Caixa Postal No. 571, Rio de Janeiro, Brazil.
Charles le Maistre, 28 Victoria St., London, S. W., England.
A. S. Garfield, 45 Bd. Beausejour, Paris 16 E., France.
H. P. Gibbs, Tata Sons, Ltd., Navsari Building, Fort Bombay, India.
Guido Semenza, No. 10 Via S. Radegonda, Milan, Italy.
Lawrence Birks, Public Works Department, Wellington, New Zealand.
W. Elsdon-Dew, P. O. Box 4563, Johannesburg, Transvaal, Africa.

A. I. E. E. COMMITTEES

The list of committees is omitted from this issue, as new appointments will be made for the administrative year commencing August 1. The new committees will be listed in the September issue.

A. I. E. E. REPRESENTATION

A complete list of A. I. E. E. representatives on various bodies will be published in the September issue.

A. I. E. E. SECTIONS AND BRANCHES

A complete list of the Sections and Branches of the Institute, with the names of the chairmen and secretaries, will be published in the September issue of the Journal.

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Splices and Tapes.—A booklet, 8 pp., describing the important properties of tape, how they may be recognized, and containing instructions for making a proper splice or joint. The Okonite Company, Passaic, N. J.

Nickel.—Booklet, 20 pp. Describes the nickel products and alloys of the British American Nickel Corporation, Ltd., L. J. Buck, U. S. Sales Representative, 342 Madison Ave., New York.

Automatic Stokers.—Bulletin K-1, 4 pp., describing Type K Stoker for operating boilers ranging up to 200 h. p. Combustion Engineering Corporation, Broad Street, New York.

Electric Heat.—The name of a new miniature publication, devoted to industrial heating, published by the Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

Electric Steel Castings.—Buls. 1-33. A series of bulletins on electric steel castings, issued by the Nugent Steel Castings Company, formerly the Electric Steel Company, Chicago, Ill.

Farm Line Extension Transformer.—Bulletin 2025, 8 pp. Describes a new ½ kv-a. transformer, designed and built on the same principles as the largest power transformer for which a high efficiency and very low core loss is claimed. Pittsburgh Transformer Company, Pittsburgh, Pa.

Contact Point Manufacture.—A bulletin describes the latest addition to the line of special and automatic machinery for the working of rare metals, rods and wires, built by the General Engineering & Supply Company, 160 Fifth Ave., New York, for the manufacture of electrical contact points.

Air Preheater.—Bulletin A-5, 12 pp. Describes the Howden-Ljungstrom air preheater, for economical steam generation, the recent invention of Frederick Ljungstrom of Stockholm. James Howden & Company of America, Inc., Wellsville, N. Y., in conjunction with the parent company of Glasgow, have concluded an arrangement whereby the sole marine license has been transferred to these companies. The air preheater will be made at Wellsville for stationary purposes, and the first lot, twelve in all, are now under construction for the International Paper Company.

NOTES OF THE INDUSTRY

The Sherwin-Williams Company, Cleveland, Ohio.—L. F. Mullen has been appointed Sales Insulation Engineer for the Eastern District. Prior to July 1, Mr. Mullen was connected with the Westinghouse Elec. & Mfg. Co., in the Insulation Section at East Pittsburgh and St. Louis.

General Electric Company.—Franklin S. Terry, co-manager of the National Lamp Works, Nela Park, Cleveland, was elected a vice-president of the General Electric Company, and B. G. Tremaine, also co-manager of the National Lamp Works, was elected a director of the G. E. Company at a recent meeting of the board of directors held in New York City.

Line Material Company, South Milwaukee, Wis.—New branch offices and warehouses have been established at 524 East 134th Street, New York City, in charge of K. M. Kline, Eastern Manager; and at 128 Sidney Street, Cambridge, Mass., under the supervision of H. J. Eslow. The branch office and warehouse at Albany, N. Y. will be discontinued, as these two new offices will serve the territory.

Pelton Water Wheel Company, San Francisco, Cal.—E. M. Breed, for several years past, assistant manager of sales, has been appointed sales manager for the company with headquarters at San Francisco. Mr. Breed has had wide experience in hydroelectric work, having been connected with the company in various capacities for the past fifteen years.

The National Carbon Company has installed a completely equipped Emergency Service Plant where motor brushes, contacts, etc. can be secured on short notice, on the seventh floor of Arrott Building No. 3, Pittsburgh. This is the third of a series of emergency service plants operated by the Carbon Products Division of the company, the others being located at 237 East 41st Street, New York, and at 560 West Congress Street, Chicago, Ill.

Standard Underground Cable Company, Perth Amboy, N. J.—George H. Hawley has been appointed manager of the Metal Departments, to fill the vacancy caused by the death of C. C. Baldwin, which occurred on June 7th last. Mr. Hawley has been production manager for the past three years of the departments in question. He has had an unusually wide experience in such work, prior to his connection with the Standard Company having been with the National Conduit and Cable Co., and the American Brass Co.

Dr. L. H. Baekeland, of Yonkers, N. Y., Honorary Professor of Chemical Engineering in Columbia University, has been made "Officier de la Legion d'Honneur" by the French Republic. In 1919, King Albert of Belgium bestowed a similar distinction upon Dr. Baekeland, making him "Officier of the Order of the Crown of Belgium." Dr. Baekeland is specially known by his research work in chemistry and his chemical inventions, notably Velox, Bakelite, etc. He is president of the Bakelite Corporation and of the General Bakelite Company. During the war he was a member of the Naval Consulting Board, the Nitrate Board and other committees of the National Research Council. He is a past-president of the American Institute of Chemical Engineers, the American Electrochemical Society, and the Inventors Guild.

The Brenner-Moxley-Mervis Company, of Chicago, has been organized for the production of copper rods and drawn copper wire for power transmission, and eventually for various allied products. The new company, which has a paid-in capitalization of $600,000, has acquired an eight-acre tract of ground on South Kedzie Avenue, and now has under construction the first unit of a plant which will eventually cover nearly the whole of the site. The unit now being erected will have a frontage on Kedzie Avenue of 116 feet and a depth of 388 feet, and will cost over a half million dollars. It will consume approximately 100,000,000 pounds of copper annually and require 4000 horse power to operate. The president of the new company is Nathan T. Brenner, head of the American Insulated Wire & Cable Co., and the vice-presidents are William J. and George T. Moxley, also president and secretary respectively of William J. Moxley, Inc. N. T. Brenner, Jr., and M. B. Mervis, both of the American Insulated Wire & Cable Co., are respectively treasurer and secretary.

Arc Welding Patents Upheld. As a result of a hearing in the United States Patent Office on May 3, 1923, in the case of Waters vs. Holslag, a decision was recently rendered upholding an earlier award of the Examiners-in-Chief, giving priority to Claude J. Holslag, chief engineer of the Electric Arc Cutting & Welding Company, Newark, N. J., in the matter of various patents relating to apparatus and methods of arc welding, cutting and repairing with alternating current. One of these patents, No. 1,305,362, issued June 3, 1919, broadly covers the use of an arc from a transformer, irrespective as to how the transformer is constructed. The decision affirmed stated in part that "the gist of the broad invention is this new use for an old apparatus. Ex post facto, the application seems obvious, but the long want for such an apparatus in the welding art, unsatisfied, as appears from the record, until the present system for use of this apparatus, long known and used in other relations was devised and found favor, indicates a high degree of invention."